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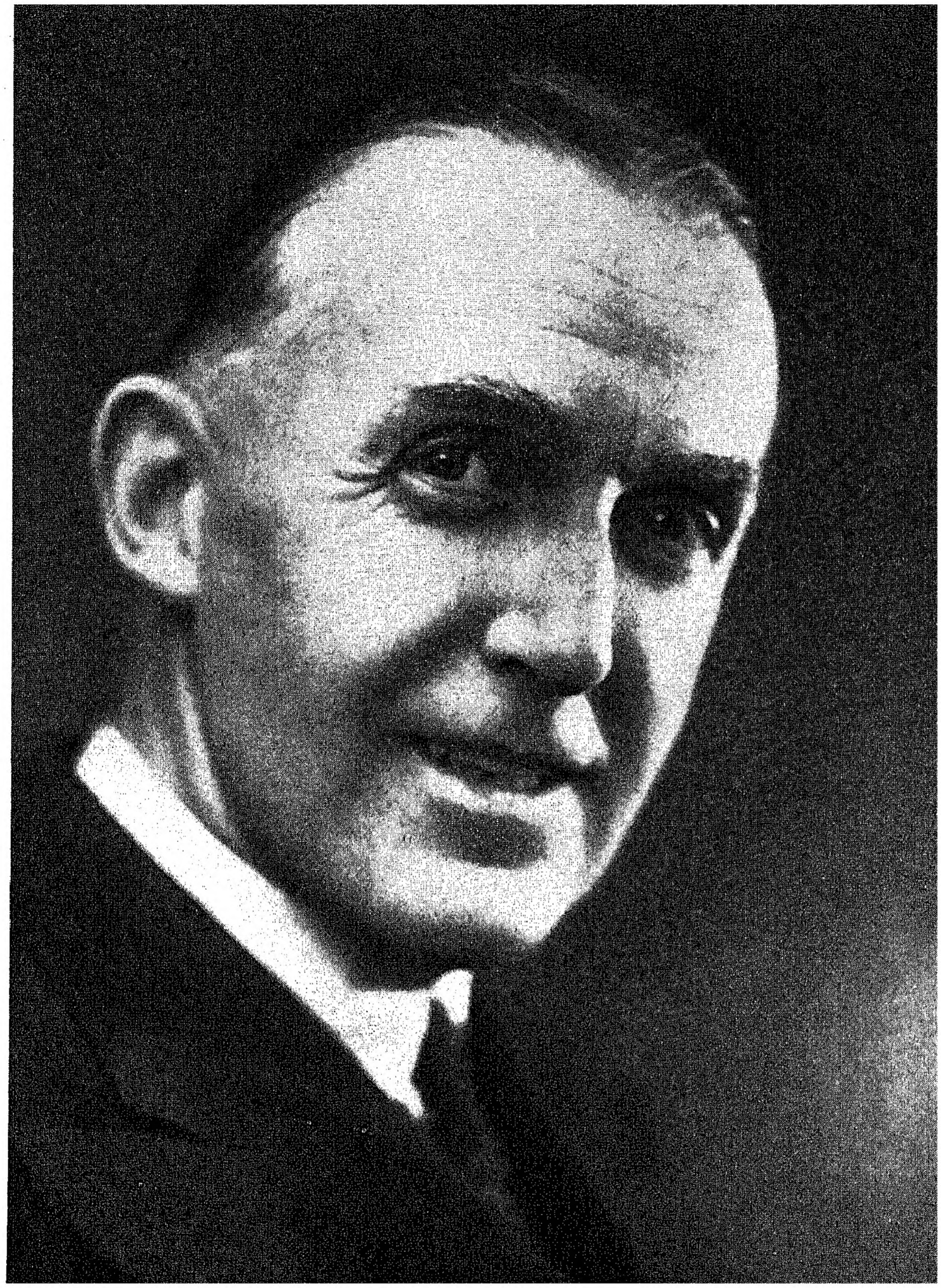

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VOL. 78.

INAUGURAL ADDRESS

By J. M. KENNEDY, O.B.E., President

(*Address delivered before* THE INSTITUTION, *24th October*, 1935.)

In this Silver Jubilee year of His Majesty's reign there has been, quite naturally, a considerable amount written and spoken of the achievements of the past 25 years and a certain measure of self-satisfaction shown in many directions as to advances in civilization. One wonders sometimes, however, whether that veneer of civilization is more than skin deep. Could one but glimpse at the world from an outside point of view, the manifestations of the human race must resemble the volcanic earth on which they live—at times in peace, but ever and again with premonitory rumblings the crust is broken and hostilities break out without adequate cause visible from outside.

It is not for me, however, in a discourse to this Institution to devote time to the international situation which is causing us all so much thought and anxiety; let us turn to what the outside observer would see in this country, where, at any rate, we may claim to a reasonably stable condition of affairs. He would see at once that we have a rich and fertile land with many natural features of great beauty; but on closer examination the salient facts which would emerge from such an observation would be:—that a vast population is crowded into and around industrial centres; that those centres are for the most part—especially when trade is busy—enveloped in a pall of smoke and grime in which the majority of the inhabitants spend the greater part of their lives; that hand labour is gradually being replaced by mechanical power, and a large amount of labour so displaced is unable to find further employment; that there are certain depressed areas in which unemployment is particularly rife, owing to the dying out of industries or their transfer to more suitable areas.

The growth of civilization has undoubtedly brought in its train problems the gravity of which is only now being appreciated. It is now recognized that these have been allowed to develop and to reach their present magnitude owing to lack of forethought and absence of planning for the future, during the rapid industrial expansion which has taken place in the last 50 years.

Many brains are at work endeavouring to find a solution of these difficulties—or I should say solutions—because there is no doubt that no single remedy would touch more than their fringe. Every branch of industry must therefore contribute its quota, some more and some less, depending upon its individual circumstances, and it would indeed be strange if the electrical industry—said to be the fifth largest industry in the country—were unable to make some very effective contribution.

As regards the overcrowding of population into industrial areas, the most striking instance is no doubt the Metropolis, where we have 10 million people, a quarter of the whole population of Great Britain, located within a radius of 25 miles from Charing Cross. Some attempt has been made to deal with this problem by the establishment of garden cities such as Letchworth and Welwyn, but the absence of national planning has resulted for the most part in chaotic development round those centres which have been able to attract industry.

Undoubtedly one of the attractions offered is the provision of a cheap supply of electric power, and any steps which can be taken to ensure the availability of this over wider areas will help to bring about the decentralization of industry which is so desirable. To this end, cheap power must of course be available for domestic as well as industrial purposes, as it would in these days be futile to attempt to repopulate rural areas unless the usual amenities of urban life are made available; and in this respect an electric supply can play a most important part, not only directly for lighting, heating, and cooking, but also indirectly by the economic installation of pumping-plant for communal water supplies.

Let us consider next the question of amenities—this pall of smoke and grime under which millions of our population are condemned to live. Everyone is willing to admit the existence of a grievance—of a wrong which

wants righting—and the cure is in the hands of those who are engaged in industry as a whole if they would but realize their collective responsibility and have the necessary courage. The absence of any initiative to put things right and the tendency to let things drift are, however, predominant. The argument that "it is anybody's business but mine" displays that aloofness of mind which is perhaps typical of our stern individualism. In some circumstances this may be due to an innate shyness, which in matters of less importance would be laudable on the part of those who, although capable of helping, do not wish to be accused of self-seeking; and so abuses, though acknowledged, continue to grow unchecked.

There is no doubt that this smoke problem can and must be overcome, but, now that the abuse has gone on so long, we cannot expect effective legislation on the subject until we are able to show that alternative methods for heat and power are available on an economic basis.

The electric supply industry may justly be proud of the fact that it has shown how coal can be utilized for the production of light, heat, and power, without the emission of grit or noxious fumes at any stage of the process—a claim which cannot be made by any alternative methods, although improvement has also been brought about by the utilization of smokeless fuel and gas.

Our constant aim, therefore, must be to take all steps necessary to reduce the cost of electricity to the consumer, so that we can go boldly forward and say that at least one alternative is universally available on terms which will not involve any addition to the household or industrial budget, and then—and only then—can we hope for effective legislation on the question of smoke abatement.

In this connection I would refer also to railway electrification—the development of which would obviously have an appreciable bearing on the reduction of smoke and grit, especially in urban areas. Although many of us believe that the electrification of a considerable extent of the main lines and of all suburban services would be profitable even with current at its present cost, any reduction in the cost of current will help to accelerate developments.

Another aspect of this problem which merits attention is the advantage which would result from the more general adoption of the electric road vehicle, both of the trolley and battery types. For urban work there appears to be a definite field awaiting development, and such conversion would help to diminish the amount of imported petrol, increase the amount of coal mined in this country, and improve the amenities of the streets.

Then we turn to the much vexed question of unemployment. In spite of the fact that there is a record number of persons in employment, there are still nearly 2 million unemployed. The chief difficulty obviously arises from the fact that the number of persons of employable age has been steadily increasing owing to the increase in the birth rate after the War and the increase in the average span of life. Although the optimum population in Great Britain as a whole may be reached within the next decade, the employable population will definitely increase during the same period and is not likely to decline appreciably in the next 20 years.

Attempts may be made to reduce the numbers of employable persons by compulsory retirement at 65—a solution obviously fraught with many difficulties. A more hopeful line of attack would appear to be in raising the school-leaving age to 15 and in a partial return, at any rate, to the apprenticeship system, which has been sadly neglected in late years. Such a course would have the effect of reducing the employable population by about half a million.

But whatever improvement can be effected by a possible reduction in the number of those of employable age, there would still remain a large number who, under present conditions, are condemned to a life of idleness, and the main question is, obviously, how to put them to work and to keep them permanently in remunerative employment. I cannot agree with those who fear that any steps which could be taken to plan industry so as to re-absorb the present number of unemployed would place us in a difficulty should there be some great revival of trade. If such revival should take place and resulted in a potential shortage of labour, I am certain that scientific and technical development would soon find the necessary remedy by increasing the amount of power used in relation to the numbers of employed and so decreasing the amount of labour required per unit output of work.

It may certainly be claimed that the electrical industry as a whole has been helping to stem the tide of rising unemployment during the last 10 years. The total numbers employed in manufacturing, contracting, and supply, have increased from about 200 000 to 330 000 in this period. In the supply section of the industry the increase has been rather more rapid, in spite of the co-ordination of generation brought about by the 1926 Act. Fig. 1 shows that the numbers employed in generation have remained practically constant during the last 8 years, whereas the numbers engaged on distribution and administration have more than doubled. As the closing down or limitation of output of generating stations is bound to result from time to time in a reduction of personnel in individual cases, every effort should be made to train the labour thus displaced so that it can be transferred effectively as opportunity arises.

Any speeding-up in the development of electricity supply both for domestic and for industrial purposes will bring in its train a large amount of work for both the manufacturing and the contracting branches, and will obviously have a favourable reaction on the question of unemployment.

Railway electrification too has an important bearing on this question. It has been estimated that any comprehensive programme of railway electrification would employ directly or indirectly over 100 000 men, which would be no mean contribution to the solution of unemployment, and although it must be admitted that the ultimate effect would be to reduce the number of permanent railway employees for any particular programme of train mileage, yet the potential and probable increase in services, coupled with the additional personnel required on electrical works, would go a long way to counterbalance this disadvantage.

Brief reference might also be made to the criticism that railway electrification would bring about a reduc-

tion in the amount of coal required. Here, again, it must be agreed that for any particular density of service the coal would be appreciably reduced, although it must be pointed out that the total coal used by the railways is less than 6 per cent of the total mined; and as services are increased and accelerated to deal effectively with the growing traffic requirements, so will this objection be mitigated. Furthermore, if the normal supplies of electricity are augmented by the addition of the supplies to comprehensive railway-electrification schemes, the overall cost of electricity will be reduced, and this will allow of reductions in tariffs to consumers, who, in turn, will buy more current and therefore require a greater consumption of coal.

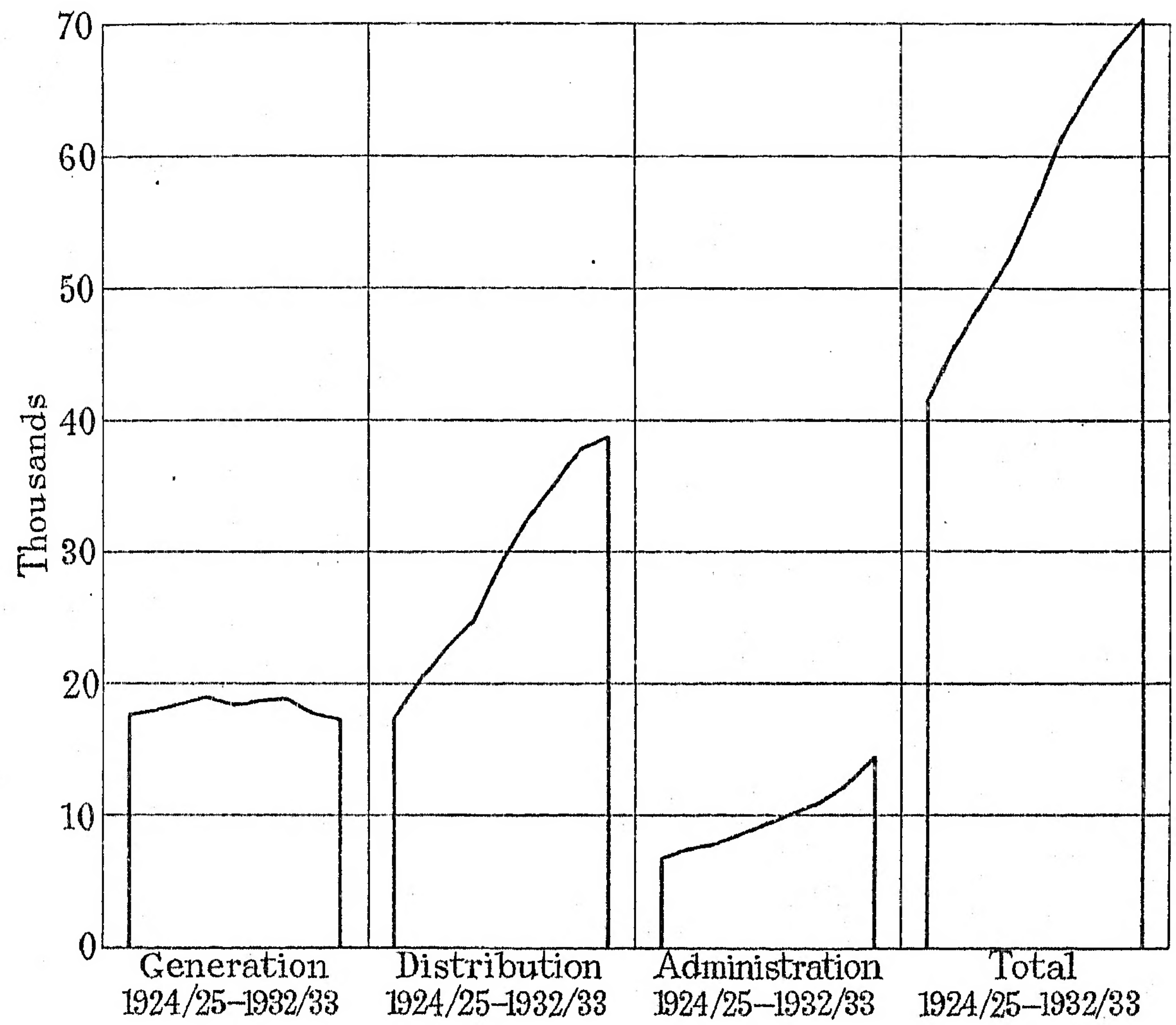

Fig. 1.—Number of staff and workmen in electric supply industry in authorized undertakings, 1924/25 to 1932/33.

As any comprehensive programme of railway electrification would probably be spread over a period of 10 to 15 years or longer, I consider that the ultimate results on employment or coal consumption need not cause any apprehension, and it would certainly help employment during the period of construction.

The help which electricity can give, and is, in fact, under a moral obligation to give, to the solution of all these problems depends upon its greater availability and a reduction of its cost. My critics will no doubt point with pardonable pride to the growth of the electric supply industry in the last decade, and I would be the last to decry in any way what has been achieved.

Let us pause for a minute and see what has been accomplished. In the period 1924 to 1933 the sales of units by authorized undertakers in Great Britain have increased by 163 per cent, the average revenue per unit sold for lighting, heating, and cooking, has decreased from 4·20d. to 2·27d., and the average revenue per unit sold for all purposes has been reduced from 1·85d. to 1·37d. If, however, we analyse these figures we find that this reduction of 0·48d. per unit in revenue has only been possible owing to the reduction of the total costs of generation (including capital charges) from 0·97d. to 0·52d. per unit sold and a small reduction in the amount per unit set aside for the relief of rates; there has been no reduction in the cost per unit of distribution.

I emphasize these facts, not with any view of criticizing what has happened in the past, but in order to draw attention to the problems which lie ahead. No one could fail to be impressed with the magnitude of the reduction in the cost of generation—a reduction, furthermore, which has been fully reflected in the average price charged to the consumer. It certainly seems evident that on the generation side the industry, in conjunction with the Central Electricity Board, which is of course an integral part of the industry, can be said to have put its house in order. The full economies of the grid system have not yet been realized and it may be confidently anticipated that some further reduction of generating costs will be brought about in the next 2 or 3 years, resulting from more effective control of the stations in all regional areas and from the reduction in the percentage of spare plant to a working margin of, say, 20 per cent over the aggregate maximum demand.

Although such further reductions can only be of minor

significance as compared with the reduction achieved in the last 10 years, it is, nevertheless, essential that the best possible use should be made of our nationally co-ordinated system of generation. But if the Central Electricity Board is to achieve the best results, the industry must give it their wholehearted co-operation and support, with a united will to enable the raw material of the distribution undertakings to be produced at the lowest possible cost.

It is disappointing to find that, in spite of the most adequate explanations which have been given as to their functions and objects, the Central Electricity Board and the grid are still the subject of much ill-informed criticism, no doubt owing to a lack of knowledge or appreciation of the Act of 1926. After all, the Central Electricity Board is only doing for the industry collectively what several of the larger undertakings, owning two or more stations, have done for themselves in a smaller way.

It is a simple matter for anyone who has studied technical and economic problems to see that the interconnection of power stations and the pooling of resources, from the point of view both of reducing spare plant and of using the most economical plant to the best advantage, is a sound policy provided the savings are sufficient to pay for the cost of interconnection over a series of years.

In so far as the interconnection is to be justified by the reduction in spare-plant capacity, it is obvious that it will take several years before the reduction can be effected, but it may be of interest to point out that whereas in the years 1929 and 1930 the spare plant as a percentage of the aggregate maximum demand was 83 per cent, it has been gradually reduced to 82, 79, and 62 per cent respectively in each of the 3 succeeding years. This reduction of 21 per cent since 1930 represents a freeing of approximately 1 million kilowatts of plant which would otherwise have been kept in reserve. If we put the cost of that plant at a net figure of only £10 per kW, it appears that a saving of £10 million has already been brought about, or more than one-third of the whole cost of the grid.

With the further reduction in spare plant capacity to a figure of say 20 per cent, it will be clear that the net value of plant which is freed for commercial operation will be in excess of the whole cost of the grid, and very considerable additional economies will result from the co-ordinated control of all generating resources. But if those advantages are to be shared equitably by the whole industry, it is essential that all sections should play fair and no one section try to score at the expense of another.

I cannot leave the subject of generation without paying due tribute to all those who have by their efforts during the last decade brought about the improvement to which I have referred; those responsible for the design, manufacture, and operation of the plant, all deserve the highest credit for the results which have been achieved in greatly increased thermal efficiency, reduction in overall cost, and elimination of grit and noxious fumes.

In order to consider what further improvements can be effected, I would draw attention to Fig. 2, which shows how the total revenue from working is appropriated. Capital charges as a whole account for practically half the total revenue, and a preponderating part of the revenue is absorbed in distribution costs.

It may be interesting to point out here that the annual turnover of the electric supply industry only amounts to 15 per cent of the total capital expenditure, whereas in the gas industry the turnover is over 30 per cent, and in the Post Office the revenue is over 45 per cent of the capital expenditure. Of these percentages, capital charges represent about 7 per cent, and it is clear, therefore, that they are of far greater relative importance in our industry than in the other two cases which I have quoted.

The importance of obtaining capital at the lowest possible price is evident from the simple statement that if the charges could be reduced by 1 per cent on the capital expenditure, the average revenue per unit could be reduced by nearly 7 per cent. Although there is always a public demand for an investment with a high return, it is recognized that such return is coincident with some measure of risk and that those who subscribe their money are willing to take that risk, but there is no dearth of money available at low rates of interest where the risk is negligible, as in the case of most electricity supply undertakings.

Allowing, however, for any possible reduction in the cost of generation capital and for any further reduction in operating costs due to co-ordination, the improvement which may be effected in this direction must be small compared with what has already been achieved. To maintain or accelerate progress, therefore, we must look to the distribution side to effect the necessary economies. Possible improvements in distribution may be summarized under the following heads:—

(1) A reduction in capital expenditure by co-operation between adjoining areas;
(2) A reduction in capital expenditure by economies in design and construction;
(3) A reduction in the percentage relationship of annual distribution costs to capital expenditure;
(4) An increase in the number of units sold per £ of capital expenditure.

With reference to the first point, there is no doubt that some economy in capital expenditure can be effected by co-operation between undertakers whose areas adjoin, in giving supplies to streets or villages on or near the boundaries, especially in those cases—which are rapidly increasing in number—where the magnitude of the demand warrants a duplicate supply.

As regards my second point, there is still a very wide divergence in practice and design among different authorities, which brings about very material differences in the cost per mile both of underground cables and of overhead lines. A freer interchange of ideas and experiences is obviously desirable, and we may hope that our newly formed Transmission Section will be of material assistance in this direction.

Can we not also reduce the costs of manufacture of apparatus by bringing about a greater measure of standardization, especially in the design of cookers, on which so much thought has been expended but on which so many differing ideas are still held?

As regards the third point, I would draw attention

to Fig. 3, which shows a fairly straight line relationship between the annual distribution costs (including capital charges) and the capital expenditure. In the first year, the costs represented approximately 15 per cent on the capital, and in the last year 13 per cent. I have already referred to the need for reducing capital charges, which are such a large proportion of the total costs. The cost of administration must be carefully overhauled to see that all possible economies are effected. It is also essential to reduce tariffs, in order, as far as possible, to eliminate surplus profits and thus obviate unnecessarily high assessments for income tax and local rates.

The fourth and probably most important point is the sale of a larger number of units in relation to the capital expenditure.

Assuming that the distribution costs can be reduced to 12·5 per cent on the capital, 30d. is required annually to meet the costs and charges incidental to each £ of capital expenditure; and therefore, if only 30 units are sold per £ of distribution capital, the distribution costs must be 1d. per unit. In the last 10 years the number of units sold per £ of distribution capital has fallen from 48 to 41, but this has to some extent been counterbalanced by the reduction, which I have already mentioned, in the percentage relationship of costs to capital, and the result has been a small increase in distribution costs from 0·76d. to 0·77d.

There may no doubt be many arguments put forward to account for this lack of improvement, among which might be mentioned the spreading of supplies into rural areas and the connecting up of a considerable number of consumers with a lower average income than those previously supplied.

I am not at all sure, however, that the former contention is correct; an investigation recently made shows that the capital expenditure per consumer on transmission and distribution in some typical rural areas is less than in many urban areas. Also the capital cost per consumer, for the country as a whole, has decreased steadily each year in spite of the spreading into rural areas. It is obviously impossible to make any generalization in this respect, but I have always maintained that the much lower cost of overhead transmission and distribution in rural areas would go far to balance the lesser number of consumers per mile.

As regards the latter contention, whereas it is true that the consumption of the consumers with a lower average income should normally be less than that of those more fortunately placed, yet the present average overall consumption per consumer for lighting, heating, and cooking, is only about half the potential requirements of the smallest household for lighting and cooking only. It would appear, therefore, that if sufficiently attractive tariffs were offered, there would be every

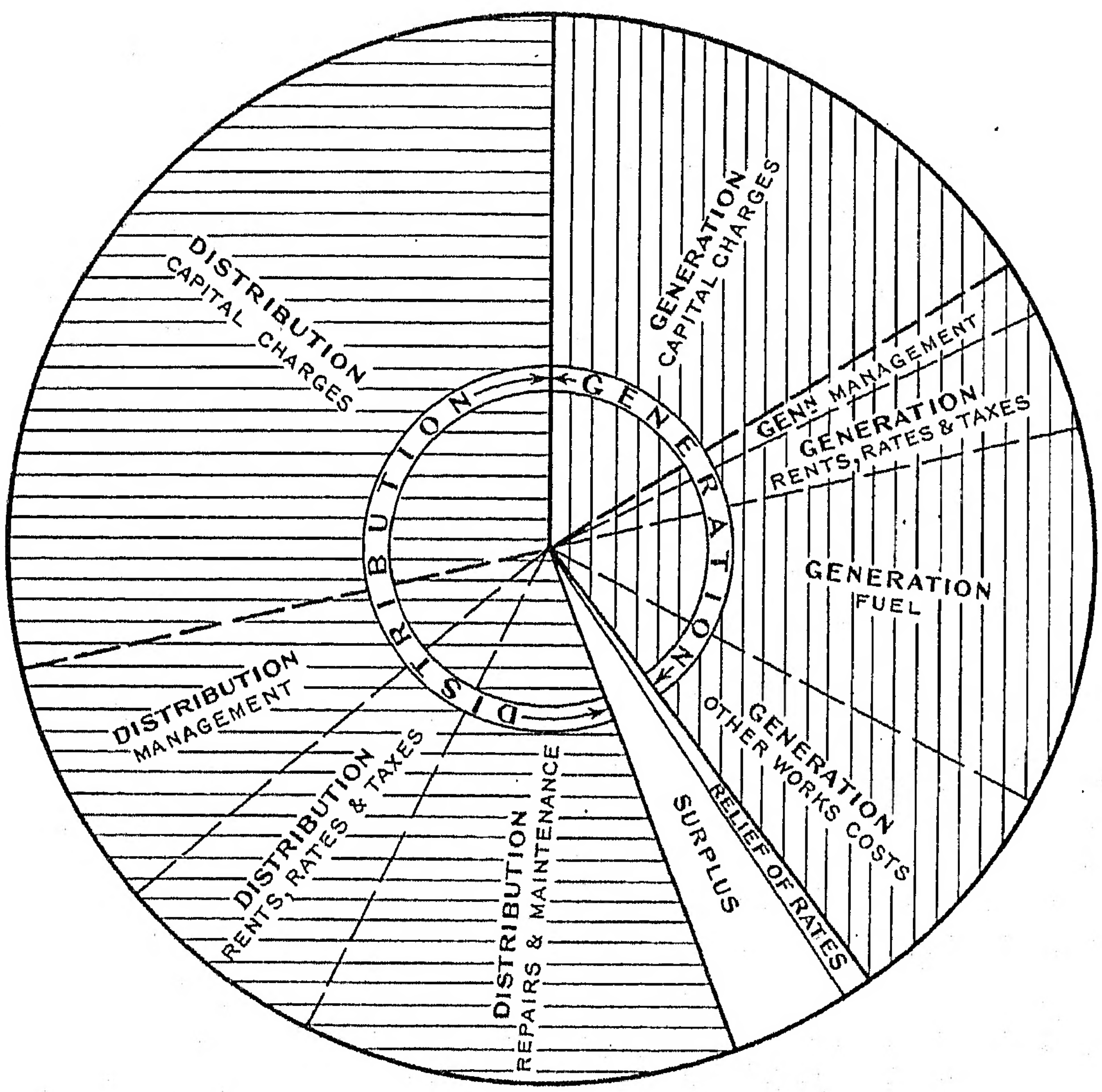

Fig. 2.—Diagram to show how revenue is appropriated.

reason to anticipate a substantial increase in the average number of units sold both per consumer and per £ of capital.

I cannot stress too strongly the need for careful and systematic investigation into all these suggested methods of improvement, on which depends the successful development of the electric supply industry. I know that many critics will say that there is no need to worry; that sales are increasing sufficiently fast; that just over 3 million consumers have been connected up in the last 5 years; and that generally the industry is in a very flourishing condition.

While certainly not denying these statements, I venture to suggest that the position is not quite so satisfactory as they might lead one to suppose. In the first place, although the last 5 years have admittedly seen a large increase in the number of consumers, it must be recognized that in this period over 1 000 000 new houses have been built which, with the accompanying new shops, offices, and other incidental premises, represent, say, 1 200 000 potential consumers, the bulk of whom must have become actual consumers for lighting, at any rate, in all areas where supplies are available, with little if any sales effort on the part of the electricity supply undertakings. Consequently, the real inroad into the potential consumers who existed 5 years ago has only been at the rate of 360 000 (or approximately 3 per cent) per annum.

The present position, as I see it, is that although progress in the past few years has been on the whole satisfactory, it has had the adventitious aid of steadily reducing generation costs, coupled with a programme of new house-building which has probably accounted for not far short of half the total gain in consumers. Although the increase in sales to date has exceeded the estimates on which the Central Electricity Board framed its tariffs, and we have no apprehension, therefore, as to the financial result, the present is not the time for complacency if the industry is to be of real help in solving the problems to which I have referred.

It must always be remembered that the progress which has so far been achieved relates in the most part to supplies to those who have most money to spend. The nearer we approach to saturation, the greater will be the difficulty of maintaining the same rate of progress unless there is a more intensive effort and, in the majority of cases, an appreciable reduction of tariffs.

But to my mind one of the greatest dangers of complacency at the present time is the phase of keen competition upon which we are now entering, for both the domestic and the industrial loads. Doubtless our strongest rival in the domestic field is the gas industry, and one cannot but feel admiration both for their originality of ideas and for their imitative ability. Let us give them all the credit they deserve for Mr. Therm and his antics, which we may or may not admire, but which we cannot help noticing. Let us also give them credit for the self-regulating oven which our manufacturers—somewhat tardily in my view—are now developing, and let us note how they are copying our two-part tariff; but note also how that tariff, when introduced, is offered universally over a great area of London to over 1 million consumers, and not in a score of different scales and forms as is the case with electrical tariffs in the same area.

Another form of competition which is certainly proving attractive to some potential consumers is the slow-combustion stove, for which the manufacturers are prepared to guarantee a maximum yearly cost of fuel. With the heat-storage type of electric cooker of course there is no reason why a supply authority should not give a similar guarantee, and, although it may be an impracticable ideal to offer the same guarantee in connection with the more usual form of electric cooker, it is obviously a point which would appeal to many potential consumers.

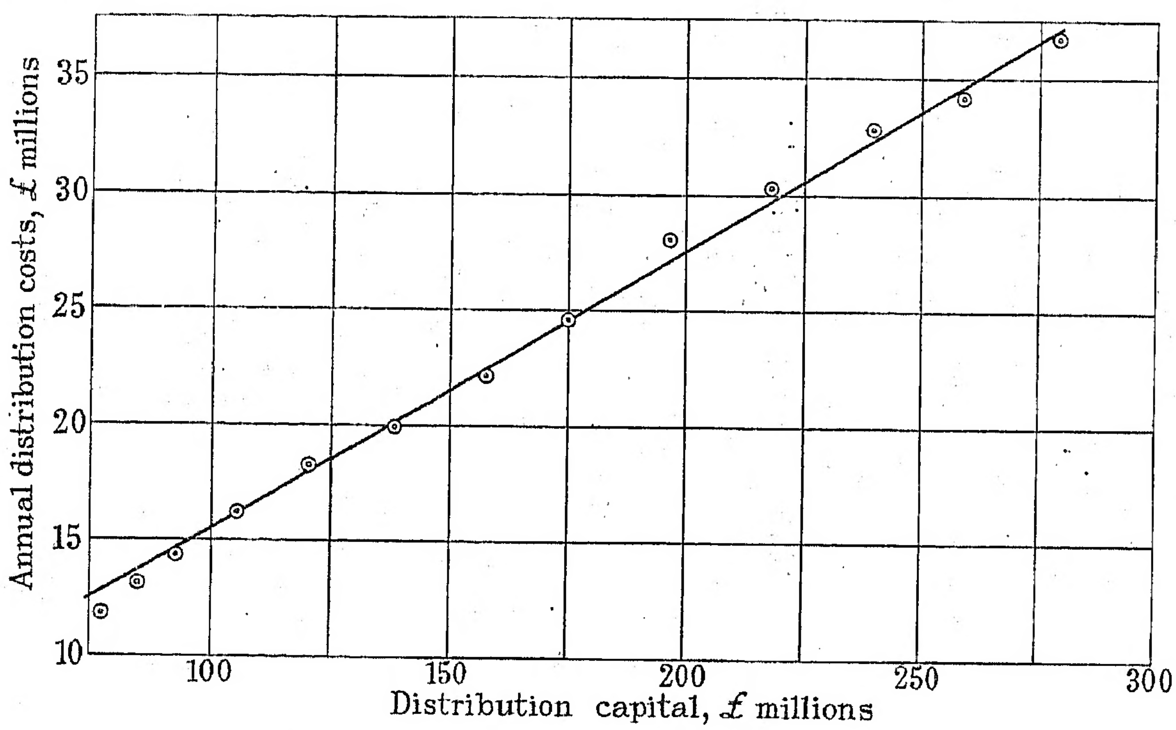

Fig. 3.—Relation between total annual distribution costs and distribution capital, 1921/22 to 1933/34.

Let us not run the risk, therefore, of trading on our reputation; self-congratulation is all very well up to a point, but complacency is apt to lead to abuses and to be most dangerous when prosperity appears to be assured. It is then that we must strive all the harder to increase our reputation and, by giving better and cheaper service, to capture and retain the confidence of our consumers. With this end in view, steps should be taken to obviate complaints which arise from such causes as the neglect of consumers' requirements, the bad regulation of voltage, excessive charges for service cables, and the complexity of forms which the unfortunate consumer has in some cases to fill in.

There are some organizations which appear to be developed upon such specialized lines that a potential consumer has to discuss his requirements with several different representatives of the undertaking, dealing with everything from the fixing of meters to the hire of cookers, each in separate watertight compartments. It may be possible to show theoretical arguments in favour of such an organization, but from the consumer's point of view it is most irritating and is likely to lead to mistakes and friction. Apart from ethical considerations, such practices defeat their own object in the long run because they lead to dissatisfaction on the part of the consumer, and a dissatisfied consumer is the worst form of advertisement which any service can have.

There are, no doubt, certain areas where particular precautions have to be taken to guard against bad debts, but I do suggest, in all sincerity, that there are many cases where the formalities incidental to obtaining a supply of electricity are unnecessarily complex and more suitable for an undertaking which is dealing in precious metals than for one selling a commodity of everyday use. If we could only induce ourselves to believe in the essential need of our service to the public at large, we should surely simplify procedure and create a more favourable atmosphere.

In order that the problems of distribution may be tackled on a scientific basis, it is essential to understand the requirements and to possess the necessary data in respect of each area, so that a suitable plan of development can be prepared.

I should like to refer here to the excellent investigation carried out on working-class houses under the auspices of the Electrical Association for Women. As already stated, a vast field is awaiting development in this direction and an intimate knowledge of the requirements of the different types of families is essential if this demand is to be catered for in an adequate manner—above all, a knowledge of the amount of money which the consumer of each type can afford for the service offered.

With consumers who are living frequently, though not invariably, from hand to mouth and without any margin for luxuries, and certainly with no desire to reduce the amount spent to-day on such pleasures as they are able to afford, it is obvious that the change-over from present methods to electricity will only be brought about if the total cost of the electric service will be not more, and preferably less, than the equivalent expenditure at present. The lower we proceed down the scale of incomes, the greater will be the need for reducing the charges for essential services and, from the social point of view, the greater is the need for the advantages which electricity can confer.

In the formulation of suitable tariffs and charges to meet the needs of the poorer classes, the investigation by the Electrical Association for Women is of fundamental importance. Much additional work of this kind will no doubt be required and much of it can best be carried out by women, and by women who should be adequately trained and remunerated for such services.

In considering the need for scientific investigation into the many technical and commercial problems incidental to electricity distribution, I am reminded of Mr. C. C. Paterson's Presidential Address to this Institution* in which he referred to the difficulty many practical and administrative engineers have in recognizing research problems when connected with their daily work; or, if they do recognize them, they fail to entertain seriously the possibility of organization to cope with them. As Mr. Paterson pointed out, an engineer is apt to consider that the paramount object of research is to discover some new product and not to elucidate problems which arise in his daily work; I would emphasize that for the successful carrying on of any business on a large scale, such as electricity supply, investigation and research are just as necessary into what may be termed commercial and psychological problems as into purely technical difficulties.

The industry has developed beyond its haphazard period of infancy; and now—as in other forms of life—it is arriving at years of discretion and should realize its collective responsibilities. All are agreed that its background of piecemeal development, of differing systems, voltages, and tariffs, has already become a hindrance and must inevitably be felt as a greater handicap in the future unless some steps are taken to deal adequately with this legacy of the past.

It must be borne in mind that in many cases differences in prices and in rates of development are governed more by policy than by cost, and that the best way of overcoming these differences is to establish, by some means or other, a measure of co-ordination in policy over wide areas.

The greater the delay in dealing with any of these problems—however they are dealt with—the less rapid will be the reduction in the cost of current and the rate of development generally. It is no reflection upon the forethought of those who were responsible for our early legislation to find, after 40 years, that their ideas are not best suited to the present conditions. Now that we have come to a realization of these problems, and appreciating, as we do, the important part which electricity can play in ameliorating the lot of mankind, it would surely amount to culpable negligence in the eyes of later generations if the electric supply industry did not take the necessary steps to provide adequately for future development.

Let us consider what the future holds in store for us. An estimate of potential electrical development was made in 1926 by Sir John Snell and put forward in his Presidential Address to Section G of the British Association

* *Journal I.E.E.*, 1931, vol. 69, p. 1.

in that year.* He gave the following consumption as an ideal to be aimed at:—

	Million Units
Domestic supplies	20 000
Industrial power	20 000
Railway electrification	7 000
	47 000

Fig. 4 shows the rate of progress in the last 10 years and indicates that Sir John's estimated output would not be reached until 1960, assuming that progress at the average rate of the last 5 years were maintained throughout this period. It will be seen that we are still a long way off—25 years—from what was considered 9 years ago to be a reasonable goal.

What confirmation of these figures can be obtained by up-to-date statistics? Long before the expiry of the next 25 years, the industry should be able to account for 10 million domestic consumers, and on the basis of Sir John Snell's estimate for domestic supplies, including shops and offices, the average consumption would only amount to 2 000 units per consumer, a consumption which would easily be reached by lighting and cooking supplies alone.

But what about water-heating? Surely within the next 10 or 15 years we can look forward to a great advance in this direction! The potential demand will certainly be there, owing to the advance in the standard of living; and although it may be rather a far-flung stretch of imagination if we reached the stage of cleanliness in which everyone had a hot bath once a day, the consumption for this service alone would amount to 58 000 million units or nearly three times Sir John's estimate of all domestic requirements!

Then, again, a small house should certainly need 2 000 units at least for space heating—a potential demand of another 20 000 million units—so that it is evident that the saturation point is receding into the far distance and that with an active sales policy Sir John's estimate could be far exceeded.

Lest I may be considered to be unduly optimistic, let me quote the sales in Winnipeg for domestic consumption of lighting, heating, and cooking (excluding all shops and commercial premises), which has risen steadily from under 1 200 units per consumer in 1921 to over 4 500 units per consumer in 1934, averaged from a total number of 40 400 premises supplied and a population of 220 000.

Turning now to industrial power, it is clear from the paper read by Messrs. F. Forrest, H. Hobson, and C. D. Taite,* at Bournemouth last summer that an increasing amount of power is being converted from direct mechanical to electrical drive; but that the total power requirements are increasing at the rate of approximately 400 000 h.p. per annum as compared with an annual increase of only 250 000 h.p. of purchased electricity. The last figures available are for the year 1930, and there have been a number of large industrial concerns changed over to a public supply of electricity since that date. It would appear, however, that a considerable acceleration in the rate of conversion will be necessary if the public supply is to maintain its position in relation to the total power requirements of the country.

The figure for industrial power given by Sir John Snell is equivalent to about 70 per cent of the total power requirements of industry as ascertained by the 1930 Census, but, if those requirements grow at the present rate, his estimate would represent less than 50 per cent of the total in 20 years' time. Here, again, it would now appear that Sir John was, if anything, conservative and that industry may easily absorb a far greater electrical output than he contemplated.

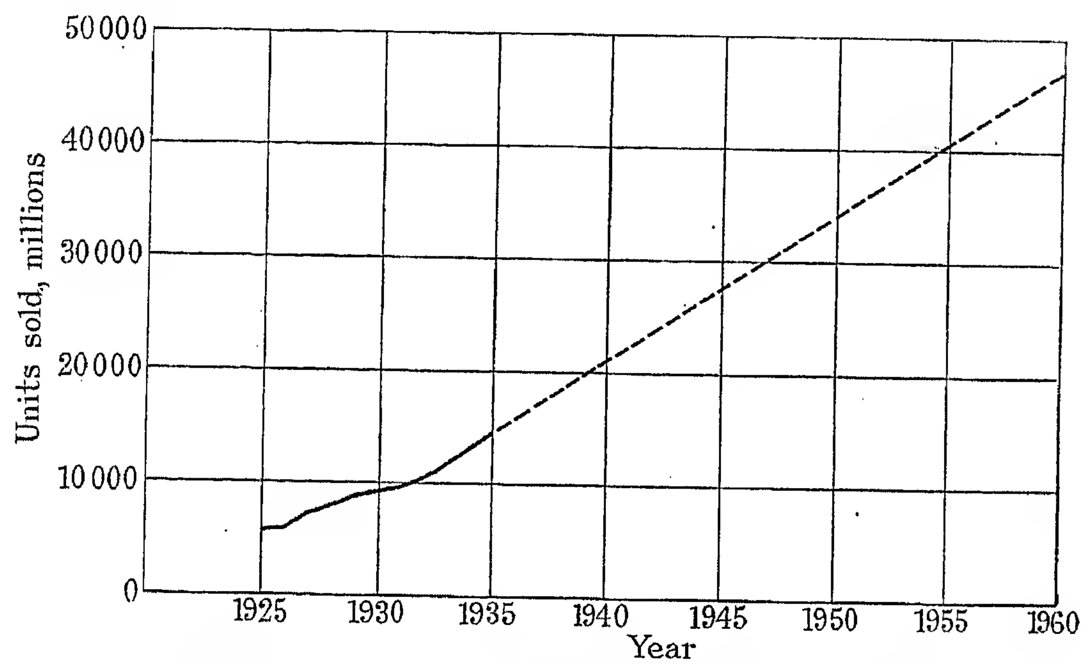

Fig. 4.—Present and estimated future sales of electricity.

Actual sales 1925–35 ————
Future sales based on rate of growth over last 5 years – – – –

* Report of the Meeting of the British Association for the Advancement of Science, 1926, p. 156.

* "Industrial Power Supply," *Proceedings of the Incorporated Municipal Electrical Association*, 1935, vol. 40.

As regards railway electrification, an estimate prepared by the Weir Committee in 1931 confirms closely Sir John's estimate; the potential demand is there and I, for one, will be surprised if the greater part of this demand does not materialize in the next 20 years.

Electricity is a commodity which is able not only to supply old wants in a new way, but always to create new wants, which will become more and more insistent as their advantages are realized. As yet the limits of future development are not only out of sight, but one might say beyond conjecture, because long before we have reached or approached any limit of saturation which we can visualize to-day, new demands of a far more comprehensive nature will have arisen.

I suggest, therefore, that we might well take Sir John's estimate of 47 000 million units as a goal to be aimed at in the next 10 to 15 years at the outside, in the confident anticipation that the potential domestic and industrial demand, as we shall then know it, will be far in excess of our present ideals.

There is no doubt in my mind that the electric supply industry has great potentialities for development, but the extent to which the industry will be able to help in solving the problems to which I referred in my opening remarks depends upon its future policy.

As a Committee appointed by the Minister of Transport is at present considering what steps should be taken to bring about an improvement in the organization of distribution, it would be inopportune for me to express any views; I would urge, however, that whatever form of reorganization is ultimately decided upon, we should one and all agree to sink our individual differences and do our best to make the scheme a success, in the knowledge that by so doing we shall be working in the national interest.

In conclusion, I should like to express my sincere appreciation of the honour of being elected President of this Institution, and I can assure the members that I shall always do what lies within my power to uphold its prestige. I have not had the advantage of some of my predecessors in being able to talk to you to-night of any scientific attainments, or to fascinate you with experiments to demonstrate the practical uses of recent scientific inventions in the electrical field. I can only claim to speak with enthusiasm of the industry in which so many of us are interested, an enthusiasm which I know is shared by many of my fellow members. If anything which I have said helps to kindle that same spirit of enthusiasm in those who are now entering the profession and gives some impetus to others, I shall not feel that I have spoken in vain.

WIRELESS SECTION: CHAIRMAN'S ADDRESS

By R. A. WATSON WATT, B.Sc.(Eng.), Member.

"A PATHOLOGIST LOOKS AT RADIO COMMUNICATIONS"

(*Address delivered before the* WIRELESS SECTION, *6th November*, 1935.)

I think the enthusiastic pathologist must, as he looks at the everyday life around him, be surprised at the vigour, the efficiency, and the cheerfulness with which that life goes on, despite the evidence, all too clear to him, of the diseases and derangements from which scarcely one of the people he sees can be regarded as reasonably free. He may even be a little piqued in his professional pride that life should go on so effectively against these odds!

And so, in radio communications, the enthusiastic "pathologist" gazes with genuine wonder, and a complex feeling between admiration and pity, at the cheerful activity of the radio engineer, at the record of his triumphs as set down, for example, in the *Proceedings of the Wireless Section*, at the evidence in his own non-professional life of the dazzling success—he may be tempted to regard it as an almost regrettable success—with which the manifold diseases and derangements of radio communication channels are surmounted, suppressed, and, indeed, frequently ignored.

It is well known that one of the most potent sources of danger to the healthy life is the reading of "The Home Guide to Medicine." But for lives so rudely healthy as those of this Wireless Section the danger is slight, and the result of the reading is more likely to be a glow of robust satisfaction. And so I propose that we should risk a rapid, and necessarily superficial, look at radio communications through the microscope of the professional "pathologist."

(1) THE LINKS OF THE CHAIN

The process of conveying intelligence by radio link is, I need not remind you, a complex one. Once the form in which the intelligence is to be conveyed has been determined, once the highly difficult problem of choosing a channel—and obtaining it when chosen—has been solved, the intelligence passes through the most alarming vicissitudes. But before considering them, half a dozen sentences on the kind of intelligence to be conveyed may be well spent. The main body of intelligence is conveyed by the appropriate modulation, usually in amplitude, less frequently in phase, of a radio carrier-wave, by morse, by speech, by picture elements, or by vision signals. But in a well-organized world, such as is the radio part of the world of to-day, important intelligence is conveyed wholly by the value of the carrier frequency used, and by the time-table of transmission. (It would be pedantic, though true, to say that the time-table is merely a part of the modulation data.) Moreover, there is a large and rapidly growing group of services in which the desired intelligence is to be extracted, more or less imperfectly, from the study at the receiving end of the space characteristics of the received field—direction-finding, radio beacons, and radio aids to navigation in general, are of this class. Complete intelligence as to the plan position and flying height of an aeroplane approaching an airport, for example, may be derived wholly from measurements of the direction of the electric forces in the signals which it emits.

In all cases we must generate and maintain our carrier to close tolerances in frequency; we must modulate it; usually we must amplify the resulting system of radio-frequency e.m.f.'s; we must radiate effectively, and we may wish to concentrate the energy in azimuth, in altitude, or in both.

The radiated energy must then spread over the varied surface of an imperfectly conducting earth, through a somewhat imperfectly non-conducting atmosphere, much of it reaching those comparatively highly-conducting regions of the upper atmosphere for which I had the privilege of coining the now internationally accepted collective name of the "Ionosphere."

Some of the emitted energy will return from the ionosphere, and will reach a particular receiving station more or less nearly simultaneously with other elements of the same energy stream which have arrived by different routes. The resulting complex of field-changes, together with a nearly infinite variety of other field-changes produced by other and desired sending stations, including the powerful sending stations which emit atmospherics, affects the receiving antenna array.

This array may have directional properties in azimuth and altitude, giving a first preference to signals from desired directions. The resultant e.m.f. which it applies to the input terminals of the receiver must be sorted out by selection of a desired band of frequencies, to the exclusion of others. This selected band must be amplified, frequency-displaced by demodulation, may be further selected, amplified and frequency-shifted, it may be "corrected" for non-linear responses in amplitude and in frequency, controlled for variations in volume due to fading, and the electrical end-product applied to a responding instrument, electro-mechanical, electro-chemical, or light-modulating, which ultimately delivers a more or less faithful, more or less interpretable, version of the desired intelligence to the consumer.

Before an overall estimate can be reached as to the utility and fidelity of the transport of intelligence, some estimate has to be reached of the imperfections of each link in the long chain of processes thus briefly outlined. At many stages the degree of imperfection can be ob-

served or measured by the engineers responsible for the design, manufacture, and test of any particular section of the communication equipment, but improvement must be guided by knowledge of the general physics of the processes. And at many other stages the communication engineer is very directly and completely the plaything of Nature, in the sense that the results achieved are affected by geophysical processes, beyond his control, and, at present, beyond our detailed knowledge. Here, most of all, does the industry of radio communication require the aid of the physicist in the diagnosis and quantitative estimation of the processes at work in the communication chain. These latter-mentioned stages are peculiarly those in which organized fundamental research, on a substantial scale, may be of service to the industry as a whole and to every individual in it, although lying beyond the scope and responsibility of any one section or element of the industry. It was to provide for the effective prosecution of work of this character that the Radio Research Board was formed, and so it is that these confessions of a pathologist become interwoven with a brief biography of the Radio Research Board.

(2) THE RADIO RESEARCH BOARD

The Board was established in 1920 " to assist in the co-ordination of radio research work carried out by the Fighting Services and the Post Office, and to provide for research work of a fundamental nature in directions where it was lacking and where it would be likely to lead to useful applications." "In the course of time it was found that the attention devoted to the second of these objects absorbed a considerably greater share of its deliberations than the attention it was found necessary to devote to the first of them." The Board consequently ceased to be responsible for the direct co-ordination of Government radio research, and devoted itself wholly to the fundamental research aspect.

The Board reports to the Committee of the Privy Council for Scientific and Industrial Research, and its programme is made effective by a financial provision of about £17 000 per year from the Parliamentary vote for the Department of Scientific and Industrial Research (D.S.I.R.), for which the Lord President of the Council is responsible to Parliament. Under the distinguished chairmanship first of Admiral of the Fleet Sir Henry Jackson and later of the present Engineer-in-Chief of the Post Office, Colonel A. G. Lee, a past-Chairman of this Section, the Board is composed of eminent representatives of science and industry, with intimate personal knowledge and experience of radio-communication problems and of the underlying physical principles.

It must be emphasized that the Board is a purely advisory body, without administrative or executive functions. It is, however, an important element in the policy of the D.S.I.R. that the Minister chooses his own advisers to constitute the Research Boards; it follows naturally that, though their functions are solely advisory, their advice is invariably followed. Moreover, the Board exercises, with the aid of sub-committees dealing with special sections of the field of investigation, a constant scientific scrutiny of, and guidance in, the conduct and progress of the research work. Its reports to the Committee of the Privy Council are, in turn, referred to the Minister's Advisory Council, the highest of the advisory bodies assisting the Committee of Council. On the Advisory Council men of the highest standing in scientific and industrial affairs serve under the chairmanship of Lord Rutherford. This Council must, among its many duties, weigh up the relative claims of research on building, food, fuel, and a host of other activities, on the total funds available for such work. On the administrative side the provision of means for the conduct of the work is, as has already been indicated, made by the Department of Scientific and Industrial Research. On the executive side the programme recommended by the Board has almost wholly been confided to the National Physical Laboratory, and in particular to the Radio Department of the Laboratory, with its two divisions, one in the main group of laboratory buildings at Teddington, and one at Radio Research Station, Slough, the main field station of the Radio Department.

There is a not uncommon misconception as to the nature of the Board's work, which is typified by the remark " Of course a lot of your Radio Board work is very hush-hush." On the contrary, the Board has no secrets! It is concerned with scientific and industrial research for the general good, and it has nothing on its programme which is of predominantly military importance. Representatives of the defence services are there as typical consumers, differentiated from the general consumer by the fact that the demands of their respective services are on the whole more exacting, the conditions of operation more difficult, than in other sections of the radio-communication industry. These service representatives, in fact, voice the demands and typify the needs which would be pressed by the most advanced and most enlightened elements in the industry generally, if only economic conditions permitted them and their clients to make full use of such responses as could be made to these demands.

It follows from this sketch that the only product at which the Board's programme aims is paper! It is *not* the function of the Board to produce designs for industrial equipment, but to elucidate the physics of the processes in which such equipment is to be employed. Industrial equipment may, and indeed does, emerge from the work, but only, in essence, as a by-product. The new tools of the physical research may prove to be themselves ready-made equipment for practical use, but that, it must be insisted, is almost accidental. The true function of the Board is to provide physical data, which are expressed on paper, and which are then embodied into the intellectual equipment of the communication engineers of the industry as a whole.

It is, I hope, a measure of the wisdom of the first members of the Radio Research Board rather than a measure of the competence of my colleagues and myself, that no single one of the problems which were entrusted to us for investigation 15 years ago can yet be regarded as completely solved! They have been supplemented by new problems, but the fundamental difficulties of the old all-embracing questions have defied conclusive resolution.

(3) WORK ON APPARATUS

For reasons which I have indicated, the most important and characteristic sections of our work have concerned the behaviour of those links in the communication chain which lie outside the transmitting and receiving rooms. They deal in part with the antenna systems, but in the main with the phenomena in the media between the transmitting and receiving arrays. We have touched most of the other stages, as, at the sending end, in McPetrie on the generation of centimetre waves, Dye on multi-vibrators and quartz oscillators; common to both ends is Thomas on the thermal and elastic properties of coils and condensers, and at the receiving end is Colebrook on amplification, selectivity, demodulation, tone-correction, and so on. Common to the antenna systems at both ends are Colebrook and Wilmotte and McPetrie on current distribution in wires, on polar diagrams of arrays, and on a variety of other array problems. But I pass over these to review especially the pathology of the medium.

(4) THE TIME OF TRAVEL OF SIGNALS

One of the most surprising gaps in our knowledge of the mechanism of propagation is that we do not yet know how fast our radio waves travel. I do not refer to anything so profound as Brillouin's classification of four different velocities for different physical components of the wave complex, but to the fact that we simply do not know how long it takes a signal on any wavelength to cross the Atlantic by whatever route it may choose. The choice of route is the main source of doubt, but the velocity in the media is also insufficiently known. The doubt on the general problem is compounded from doubts on individual problems at which we must look separately.

(5) THE GROUND RAY

The life-history of that ill-defined portion of the whole energy-stream which we call the "ground ray" is, naturally enough, better known to us than that of the "indirect rays." We know accurately what the intensity of the ground ray will be if it travels over a featureless terrain of uniform and known physical characteristics, but we have no valid way of converting this smooth, deep sea or flat and deep desert into a rough sea or a normally undulating and fertile country. That is to say, we cannot predict accurately by inspection of maps, geographic, topographic, botanic, and meteorological, the attenuation of a carrier of known frequency in its travel over any stretch of real country; we must proceed by empirical measurement or by the traditional and usually adequate methods of "guesstimation." This is one of innumerable examples, in radio and elsewhere, illustrating the remark that "The mathematician's world is still too simple to be true."

But the process of practical estimation requires as a basis such measurements as those of Smith-Rose on the electrical properties of specimens of soil, of Barfield and of Munro on the attenuation of wireless waves in passing over town and country; it is facilitated by Barfield's artifice of a "pseudo-conductivity" for use in numerical applications of the Sommerfeld theory of the attenuation of the ground ray. The value given to this pseudo-conductivity is usually determined by direct measurement over a specimen tract of country, and in rough approximation it fairly takes account of the broken nature of the ground on the one hand and its plant covering on the other. Field surveys such as those undertaken in this country by the B.B.C. engineers and others, in addition to those made by workers for the Radio Research Board, enable engineering prediction to be made with some degree of assurance, but the pathologist cannot gloss over the empirical "rough-and-ready" basis of the process, and its consequent breakdown in many important cases.

(6) REFLECTION FROM THE GROUND

The career of the ray which has never left the ground is uneventful compared with those of rays which strike the ground from above, even when they have escaped the vagaries of travel "via ionosphere." The rays from an elevated antenna, as from an aeroplane transmitter, are reflected from the ground in accordance with known optical laws, but the laws, though known, are by no means simple. Again, we have the additional difficulty that the numerical values to be inserted in the analytical expressions are insufficiently known. For the longer wavelengths it is, indeed, frequently sufficient for engineering accuracy to treat the ground as a perfect conductor, but this approximation breaks down when we come to the shorter short waves, and we are then face to face with the continuing inadequacy of our knowledge of the electrical properties of the real ground at very high frequencies. When we have found sufficiently accurately representative figures for mean conductivity and dielectric constant, we can insert them in the expressions for reflection coefficient and phase displacement, both as functions of angle of incidence. In many cases doubt will remain as to the actual area of incidence, and as to the choice of a mean normal over a broken area, but some general idea of magnitudes may be reached. These magnitudes will differentiate sharply between the component of electric force in the vertical plane of propagation and the component perpendicular to that plane. In the latter case this horizontal electric force will, from a substantially perfect reflector, be reflected at full intensity but with a phase-change of 180°, so that the direct ray and the ray which is reflected at grazing incidence from a distant aeroplane transmitter will be received at equal intensities over sensibly equal paths, but in phase opposition, giving a nearly zero resultant signal.

For the "vertical" force there is no such gross misadventure, but over an imperfect conductor the more subtle phenomena round "Brewster's angle" bring us very nearly to the same result. As the angle of incidence increases towards grazing, the reflection coefficient decreases rapidly, the phase displacement swings rapidly, and at a certain angle, depending on frequency and ground constants, the reflection coefficient falls to a minimum. Thence it rises again towards unity for grazing incidence, but now the swing in phase has risen to the order of 180°, so that the resultant of direct and indirect ray for grazing incidence is again sensibly zero. This leaves us with the delightful problem "Why do we hear the local broadcasting station at all?" The answer can be

supplied, but it is by no means so obvious as the excellent reception would at first suggest.

(7) ULTRA-SHORT WAVES

The phenomena we have discussed up to this point do at least have the merit of being substantially unchanged over considerable periods of time. Short-term variability first comes to our notice, in our survey of trajectories which begin with ground paths and only gradually extend into the atmosphere, when we observe that fading occurs in ultra-short-wave and centimetre-wave or microwave communication channels. Here observational data and theoretical explanation are alike inadequate. That the fading takes place is firmly established, but its laws are not yet formulated. It is assumed, too generally, that over the short distances to be served by these channels, energy returned from the ionosphere is negligible, since the return would take place, on the average, at sensibly normal incidence and would consequently require high electron densities. But the increasing knowledge of ionospheric reflection suggests that conditions, relatively short-lived but recurring not infrequently, do occur in which waves of the order of 20 metres length are returned at truly vertical incidence, so that waves of shorter length will be returned at moderate angles of incidence, the limiting frequency which just fails to be returned rising as the angle of incidence increases.

The explanation of short-range short-wave fading in terms of refraction in the lower atmosphere, mirage effects being produced by temperature inversions, has been qualitatively examined, but here we have additional difficulties. Little as the radio physicist knows about the detailed behaviour of his rays, he is often better informed than is the meteorologist, who still knows deplorably little about the detailed distribution of temperature in the lower layers of the atmosphere. The problem of fading in ultra-short-wave and microwave channels is left for the further probings of the pathologist.

Meanwhile it is to be remembered that ultra-short waves, if we take 10 metres as the upper limit of the ultra-short-wave band, do travel not merely to the optical distances, which are modified by refraction and made substantially longer by diffraction, but to great distances "via ionosphere."

Some years ago I called attention to the comparatively systematic summer reception at Slough of signals on 9·8- and 10-metre channels from Rome and Sardinia, and to the two annual change dates which were common to this long-range short-wave reception and to short-range long-wave reception, the latter in the "Hollingworth effect." I think now it may be taken that my cautious reference to a possible relation in mechanism between the very base of the ionosphere in the long-wave effect and its higher regions in the short-wave effect was insufficiently cautious, and that both the phenomena then discussed actually concerned the intense ionization of the lowest E-region, which certainly reaches, not infrequently, densities capable of reflecting ultra-short waves at grazing incidence. If this be so, a reversion, after this interval, to studies on long-wave phenomena in close relation with direct measurements on the ionosphere should now be productive.

As the solar cycle has advanced from its recent minimum we have had an increasing crop of long-range receptions on ultra-short waves. These are disturbing, an embarrassment of riches, and the pathologist has a new range of troubles to watch over.

As examples of these phenomena I may quote from logs of reception at Radio Research Station and at B.B.C. stations. Police transmitters in the United States, working on 9·8 metres, have been heard with "excellent intelligibility" at Slough. The ultra-short-wave approach beacon at Tempelhof Airport, Berlin, on 9 metres, has been heard at Slough. The transatlantic telephone service from Lawrenceville has been reported "commercial" on its second harmonic of 10·29 metres. Signals from Brazil on 8·7 metres, and from an unknown distant sender on 6·8 metres, have also been received at Slough. The B.B.C engineers have read the speech on the 7·01-metre sound channel of the Berlin television service, and have had signals from Buenos Aires on 7·1 metres.

(8) THE IONOSPHERE

Turning now to the rays which do systematically return from high levels in the atmosphere, we find a whole new branch of geophysics opened out by radio soundings of the ionosphere. It would be wrong for the pathologist to attempt here a lecture on the anatomy of the ionosphere; it is sufficient to note that that region is no longer the simple Kennelly–Heaviside layer, no longer even the Kennelly–Heaviside region plus the Appleton region, but a complex region of varying ionization densities, controlled by ultra-violet radiation from the sun, probably modified by corpuscular bombardment from the sun, and responding in a way which depends very much on the thermal expansion of the tenuous atmosphere in and supporting, as it were, the ionosphere.

We have, for the ionosphere as we know it to-day, still two principal regions corresponding to the Kennelly–Heaviside and Appleton regions, but the latter has two important subdivisions: one, F_2, about 250 km up, with a generally high ionization density, but attaining its maximum ionization relatively late in the day and in the year; the other, F_1, a kind of under-shelf at about 180 km, existing only during the daytime, with ionization somewhat less dense than in F_2, and with its maxima occurring nicely about noon and about mid-summer. The Kennelly–Heaviside region has shown itself no less complicated, with its recent E_2 subdivision, traceable during the daytime at about 130 km, in addition to E_1 near the 100-km level. The behaviour of E_1 and F_1 is satisfactorily explained by the simple theory of ionization by ultra-violet light from the sun, with recombination of electrons with ions as the opposing process, and without marked thermal reactions to complicate the phenomena. Appleton has, however, been brought to the conclusion that the behaviour of F_2 requires the intervention of large thermal expansions in the atmosphere. The detailed structure and the variations in behaviour of E_1 show great complexities, among them the lowering of the base of the ionosphere

in magnetic storm conditions. It may reasonably be hoped that continued application of radio methods to the study of the ionosphere will elucidate the still obscure mechanism of the solar control of terrestrial magnetic storms.

There is no cause for surprise in the complexity of the ionosphere; the only surprise would have come from simplicity. So long as there is a substantial range of wavelengths and particle velocities in the incoming stream of ionizing agents, then we should expect maxima of ionization corresponding to the depths of penetration of the particular agents best fitted to give ionization of each particular component of the atmosphere mixture. That mixture, at ionospheric levels, as at ground-level, is known to retain nitrogen and oxygen as its most prominent constituents, and these two constituents alone provide a sufficient range of atomic and molecular states to suggest reasons for several maxima.

(9) TEMPORARY INCREASES IN IONIZATION

I have already had occasion to mention the occurrence of transient conditions in which high radio frequencies are returned, abnormally, at vertical incidence. In the work of a new field station which we have, by the courtesy of the Air Ministry, been able to establish recently at Orfordness, in Suffolk, we have given special attention to the lower region of the ionosphere in relation to these abnormalities. The isolation of the site enables us to use higher powers than would be permissible at Slough, and, although the work has only recently begun, I may cite a few random examples of the return of pulses of 12 megacycles per sec., at vertical incidence, from heights which are often below that 95 to 100 km level which has, with good reason, been accepted as the normal lower boundary of the ionosphere. Four quite random dips into the records show that the ionization density (about 2 million electrons per cm^3 according to the usual theory) required for return of 12-megacycle-per-sec. trains was attained, for periods of the order of 1 sec., near the zenith of Orfordness at such heights as 96 and 92 km, nearly simultaneously with "E" heights of 140, 104, 106, and 110 km, recorded in rapid succession. Similarly, heights of 85 and 92 km were recorded within a few minutes of one another, heights of 94, 91, 86, and 89 km simultaneously with 132, 102, and 100 km, and 96, 88, 87, 89, and 92 km, on occasions when reflections at both 117 and 128 km were visible together on the oscillograph screen, followed by similar double patterns at 98 and 112 km, and, within a quarter of an hour or so, at 99 and 149 km simultaneously. In one random experiment pulses of 37 megacycles per sec. were seen, for a second or so, to be returned from the E region at about 100 km, the electron density required in this case being about 15 million per cm^3.

The general effects of the distribution of ionization in the ionosphere and many details of the distribution itself are known, mainly through the work of Appleton and his colleagues within the framework of the Radio Research Board's programme. But the details of the mechanism are still too complicated for closely quantitative application in engineering. We know that when our waves penetrate into the ionosphere their phase velocity is increased, so that they are bent back earthward; that if the density of ionization is sufficient the bending will actually direct them back to earth; that if the ionization is dense in a region where there is still a considerable gas density the waves bent earthward will be heavily absorbed, and may be immeasurably weak on their return. We know that the group velocity, which determines the measured delay with which a signal returns to us, goes down as the phase velocity goes up, but we have as yet no means of measuring the whole distribution of ionization between maxima, no adequate knowledge of the physical and chemical state of the gaseous mixture in which the ionization takes place, and so we cannot evaluate that part of the delay time which is spent in traversing any element of path in the ionosphere. We cannot evaluate, either, that part of the absorption of energy—an absorption increasing with decrease of group velocity—which takes place in the regions above the well-defined 100-km level of the Kennelly–Heaviside region and that part which is due to ionization in the regions of low free path below that level. The unravelling of the riddle of the ionosphere has been a spectacular triumph of the last 10 years, but there is a vast amount of possibly less spectacular but still fascinating and important interpretation to be done. And until it is done many of the ionospheric influences on the travel of wireless waves must belong to the pathology rather than to the physiology of radio communication.

If I have not paused here to discuss the mechanism of fading, skipped distances, and scattered radiation from the ionosphere, it is not that they are to be accepted as finished tracts of physiology. It is, first, that life is short and, second, that their qualitative description has become familiar in recent exposition. But here, again, the pathologist's duty is to point out that qualitative description is something far short of quantitative specification, and that, for example, no experienced observer would now like to be tied to a rigid definition of skipped distance, however cheerfully he would have offered one 5 years ago.

(10) THE ANGLES OF DESCENT OF SHORT-WAVE RAYS

The clearest and simplest indications of ionospheric structure are those given by sounding pulses which travel vertically upwards to, and are returned vertically downwards from, the ionosphere. But meanwhile there is much that must be learnt from the travel of signal trains over flatter trajectories. We are not yet able to say whether a transatlantic signal traverses the ocean solely by a series of "hops" between surface and ionosphere, or whether some part of the energy may not travel in a wide U-trajectory lying mainly in the ionosphere. But we are advancing to surer knowledge from the work of Hollingworth through that of Wilkins on the angles of incidence of the main rays in long-distance short-wave signalling. The observed facts may be quite briefly summarized for a typical transatlantic 20-metre channel. The normal summer-afternoon transit is made in three hops, but at sunset here the second hop strengthens and the third fades out. In spring and autumn the ray-pattern is much more complex, 10

to 20 simultaneous and separately identifiable paths being not unusual.

The evidence of delay times alone has suggested conclusions of the same general nature, but the discriminating power of the measurement of angle of incidence is shown by the Table, which sets out the computed angles of incidence for sharply triangular hops across the Atlantic, for ionospheric levels of 315, 250, and 100 km respectively. It is to be remembered that the angles can be measured to within $\frac{1}{4}°$ in the experimental work.

Table

Order of "hop"	Height		
	315 km	250 km	100 km
1	(>90°)	(>90°)	(>90°)
2	$83\frac{1}{2}$°	$85\frac{3}{4}$°	(>90°)
3	$75\frac{3}{4}$	$78\frac{1}{2}$	$87\frac{3}{4}$
4	$69\frac{1}{4}$	$72\frac{1}{2}$	83
5	$63\frac{1}{2}$	67	$81\frac{1}{4}$

As the frequency decreases, and the distance decreases, the angle of incidence also, in general, decreases, so that the longer short waves from medium distances drop quite steeply out of the ionosphere.

(11) THE INTERACTION OF RADIO WAVES

Perhaps the most profoundly and inescapably pathological phenomenon in ionospheric reflection is that interaction of radio waves in the ionosphere often called, for brevity, the "Luxembourg effect." So long as the oscillations performed by ionospheric electrons under the urge of incident radio waves are of sufficiently small amplitude, they will be proportional in amplitude to the intensity of the applied signals, and this proportionality holds in respect of their response to each of a number of simultaneously acting signals. But when the amplitude becomes large, proportionality fails and the response becomes non-linear. Non-linear response is painfully familiar to the pathologist of valve circuits, and he knows that cross-modulation results, and that two simultaneous signals, which could be sorted out so long as they did not together carry the working point beyond the straight portion of the valve characteristic, can no longer be separated out when the characteristic used is curved. So, in the ionosphere, non-linear response results in the transfer of the modulation of a powerful signal, such as that from the long-wave Luxembourg or Droitwich transmitters, to the carrier of a medium-wave signal passing through the powerfully disturbed region of the ionosphere nearly above the long-wave station. In the result we in the London district hear intelligible modulation from Luxembourg on the carriers of Munich, Stuttgart, and Berlin, from Droitwich on Scottish Regional, and so on. Here is a new limitation in the never-ending struggle to improve the ratio of wanted to unwanted signal, and although the particular team of pathologists with which I am associated has not been very specially concerned with the study of the Luxembourg effect, closer quantitative examination of the effect is of great importance to the extension of our knowledge of the physics of the ionosphere and of its effects on communications. We may note, incidentally, that a superficial examination such as can be made by any broadcast listener lends some support to the "V-shaped hop" against the "broad-U" mechanism of propagation even at medium frequencies, for Munich shows a stronger interaction with Luxembourg signals than does Stuttgart, Berlin shows a substantial interaction, and Cologne virtually none. The interaction is strong when the apex of a V-hop lies nearly over the powerful transmitter.

We know, too, that the electrons in the ionosphere most frequently impart elliptic, indeed nearly circular, polarization to linearly polarized wave trains reaching them, so that the rays returned to earth have large components of electric force perpendicular to the vertical plane of propagation. These "abnormal" components—abnormal though everyday—drive us to especial caution in the design of receiving antenna arrays, and most of all in those special arrays which form the essential parts of the radio direction-finder.

(12) DIRECTION-FINDING

It is not entirely fair to ascribe abnormal-polarization error in direction-finders to the pathology of the medium. It belongs in essence to the psychopathology of the user, who naïvely forgot the too-simple assumptions on which he designed his loop direction-finder. But it is convenient for practical purposes to lay the blame passively on the medium and then to take the active step of designing direction-finding antennas which will ignore, as far as possible, the direct and indirect effects of electric forces outside the plane of propagation.

I think it is not even yet generally realized how bad the loop direction-finder can be. The oft-quoted example of Bournemouth's triple excursion round Slough at dusk tends to the comfortable fiction that if we avoid medium-to-short waves, twilight conditions, and moderately long distances, everything will be all right. But the permissibility of the fiction depends on many other factors, particularly the factor of whether we are prepared to take a large number of bearings or whether we must do our best with one "snap" bearing. Typical results of misleading bearings in conditions where, as I suggest, suspicions have been dangerously allayed, may be quoted.

Rugby, on 78 kilocycles per sec., was observed from Slough to move through 24° in 51 minutes, and 4° in 1 minute—this at 60 miles on an October mid-afternoon.

Brussels on 16·2 kilocycles per sec. showed a wander of 14° at 180 miles.

Teddington on 80 metres gave at Slough, only 13 miles away, a circularly-polarized ionospheric ray half as strong as this direct ray, so that a loop direction-finder would normally have to deal with an "abnormal" error-producing component of alarming amplitude, even at this small distance. The loop direction-finder is, in general, a bad direction-finder!

The work of Smith-Rose and of Barfield, especially that which has flowed from their independent re-discovery of the principles due to Adcock—whom we are proud to have still as a colleague in the N.P.L., though he has

deserted radio pathology—has led to the production of good, but far from perfect, direction-finders, which will at least tell something about the vertical plane in which the signals reach the receiving station. That they are still short of perfection is suggested by the fact that a good medium-wave Adcock direction-finder gave errors of 5° and over in 5 per cent of night readings on Kalundborg (1 261 metres) at Slough.

When the stage of part perfection marked by constancy of the vertical plane indicated as the plane of arrival has been reached, we still have grave doubts as to the relation between this plane and the vertical plane passing through transmitter and receiver. Our good direction-finder points to a true azimuth of arrival, but it can offer no assurances that the signals have not strayed from the strait and narrow great-circle path, or that the azimuth of arrival points to the transmitter.

This problem can now be attacked for the first time with any hope of success, for the overwhelming defects of all save the most recent of direction-finders in respect of abnormal-polarization error left suspect their suggestions about other errors. Now that systems of very low standard-wave error are available, the problem of lateral deviations *per se* can be studied with some prospects of satisfaction.

(13) LATERAL DEVIATION

There are many reasons for expecting real and apparent lateral deviations of the received waves. The ground ray will be refracted as it passes over terrain of varying electrical properties. It will "illuminate" conducting objects such as steel structures, masts, and trees, which will re-radiate energy not readily separable from the energy of the main ray. Ionospheric rays may come from local ionic clouds, restricted patches where the ionization distribution is specially favourable for return of the signal frequency used, and these patches will normally lie outside the vertical plane containing sender and receiver. Ionospheric rays may be reflected from a layer of large area, but so tilted as again to direct towards the receiver energy which left the sender in a vertical plane other than that passing through the receiver.

That the ground ray is, in effect, deviated is common knowledge, for the best direction-finding sites in this country have "site errors" of at least single degrees, and the average site has errors of several degrees. That the ionospheric rays are not confined to the vertical plane containing sender and receiver is almost certain, the doubts inherent in residual abnormal-polarization error in early investigations of lateral deviation do not apply to the newest apparatus, and lateral deviations of 10° for a substantial fraction of the received energy must now be accepted as not improbable, though fortunately the effect is not, on medium or short waves, maintained constant over any long time-interval.

(14) SITE ERROR

A singularly difficult problem is posed by the relation of "site error" to angle of incidence. Put qualitatively, the problem is this: "To what extent does a downcoming ray utilize the site of the direction-finder?" As the angle of elevation of the incoming ray, whether from aeroplane transmitter or from ionosphere, increases, the ray will clearly be less and less influenced by the properties of the ground. But even though we had succeeded in evaluating the effective cross-section of the tube of energy directly affecting the receiver, we should still be faced with corresponding problems for corresponding tubes reflected from the ground, and be left in doubt as to the re-radiated field from other conductors. The full predetermination of the residual errors in direction-finding, even after the conquest of abnormal polarization and even over known terrain, involves such complicated functions of azimuth, altitude, ground configuration, and frequency, that the outlook is not very encouraging.

On the other hand it is fair to say that with the mitigation of abnormal-polarization error already achieved, the short-wave band is no longer to be regarded as totally unsuitable for direction-finding operations, and indeed the comparatively high angles of elevation, in association with the rapid attenuation of grazing-incidence secondary radiations, may give special advantages to short-wave working.

Hitherto direction-finders have been designed to work on vertical electric forces, but there is no inherent reason why the "abnormal" horizontal electric force should not be utilized. When this is done the attainment of extremely low standard-wave errors is made much easier, and the resulting apparatus will be a very valuable new tool in the investigation of the lateral deviation errors of downcoming radiation.

The work on direction-finding is a fair example of the manner in which an essentially propagational research drove us to researches into receiving arrays, and also of an abstract and fundamental research which threw off as a by-product a series of concrete and practical instruments, here taking the form of commercially applicable direction-finders. But again I must urge that we were not looking for a commercial direction-finder; we were looking for a research instrument which had to satisfy conditions more stringent than those of the average direction-finding operation. It happened that the research instrument did not become too elaborate or difficult in operation for use in the commercial application.

Before leaving this subject of receptive arrays we may revert to the work of Wilkins on the angles of incidence of long-distance signals. Here, again, the main and fundamental task was the measurement of physical quantities, but it involved the design of arrays and associated gear with commercial applications, and the data themselves, without awaiting a full theoretical analysis or a complete correlation with other geophysical data, provide the basis for immediate design of commercial receiving arrays for point-to-point services.

(15) ATMOSPHERICS AND THE CATHODE-RAY OSCILLOGRAPH

One line of fundamental research, which lies very near my own heart, I have left thus late because it involves all the pathological difficulties of the lines I have already touched on, and adds to them its own intrinsic difficulties of experiment, of documentation, and of interpretation.

The investigation of the nature and origin of atmospherics, in which I have had the privilege of association with Appleton, Herd, and Lutkin, is, like that of the ionosphere, one which is not usefully compressed into a paragraph or two. I will not attempt to show how much atmospherics may teach us about the pathology of wave propagation, but there is one aspect of the fundamental investigation of atmospherics, an investigation even further from completion than the others posed us by the Radio Board of 1920, that bears on a subsidiary but important theme which has appeared several times in this discussion—the theme of by-product tools. The cathode-ray oscillograph was introduced into the first programme of work of the Radio Research Board as a tool for the investigation of atmospherics. I proposed its use in an instantaneous visual direction-finder, and Appleton and I proposed its use in the delineation of the wave-form of atmospherics. With the enthusiastic co-operation of our late colleague Mr. J. F. Herd, whose early death is an irreparable loss to our team, both applications were worked out and successfully used in the work on atmospherics. But the cathode-ray direction-finder proved also to be a powerful research tool for use on signal waves, and to be a commercially applicable direction-finder with unique properties, including loop direction-finding without night-error. Then the oscillographic technique devised for the delineation of atmospheric wave-forms proved to be convenient for the study of the ionosphere. Then the cathode-ray direction-finder was recognized as a direct-reading radio-polarimeter, and so it was applied to ionospheric studies also. Then it revealed itself as essentially a radio-comparator, for the comparison of relative amplitudes and phases in any pair of antenna arrays, and so found application to the measurements on angles of incidence in long-distance channels. Now it is permitting us to work direction-finders of types which we should not have dared to introduce but for the way in which the cathode-ray oscillograph lends itself to checking line-up and performance of the gear.

So the tools of research on atmospherics have found a leading place in the equipment of every section of our programme, and the only damaging criticism levelled against them is that they tell too much. Had a benevolent Providence not delayed the development of the cathode-ray direction-finder until aural direction-finding was firmly established as of high utility, it is not impossible that the highly complex story which it tells on the nature of the incoming waves might have deterred anyone from attempting commercial direction-finding!

In this rapid review I have taken my examples almost wholly from the work with which I am directly associated. I have done so in no spirit of sinful pride! I have tried to show that the programme of the Radio Research Board is one programme and not a collection of programmes. I have tried to indicate that within the limits of our resources we are trying to advance, as a single team, along the converging lines of closely related sectional problems, towards the complete answer to a disarmingly simple examination-paper question. "S is a radio transmitter, fully specified, situated at A. R is a radio receiver, also fully specified, shown at B on this map of the world. State fully what happens at B when the key is depressed at A."

We appreciate that we are one unit in an international army of friends and allies, contributing to one another's progress, borrowing one another's kit! I shall single out no one item of work for mention among the achievements of our allies, but I wish, in closing, to take the opportunity of saying that the most powerful diagnostic aid in radio pathology, as it was in the field of the old general practitioner, is the pulse. The artifice, introduced by Breit and Tuve, of sending out sounding pulses of brief duration, has made possible the resolution of an incomprehensible resultant signal into its individually identifiable components, and has contributed more than any other single "trick of the trade" to the progress not only of the direct study of the ionosphere, but of our wider studies in the pathology of radio communications.

If I have left you with a feeling of acute dissatisfaction, I shall not wholly have failed of my aim. We radio physicists and radio engineers are remarkable people, but we have much to learn!

TRANSMISSION SECTION: CHAIRMAN'S ADDRESS

By W. FENNELL, Member.

(Address delivered 13th November, 1935.)

The Transmission Section has had a successful inaugural year under the chairmanship of Mr. Borlase Matthews, but it may be some years before its possible range of utility will be realized.

The scope of the Section is set out graphically in the chart to be found in the pamphlet containing the Rules of the Section. There is no lack of opportunity for members to produce valuable papers, both theoretical and practical.

The range includes the Electricity Acts and Regulations and is even to be taken to include suggestions for future legislation, and we may have papers dealing with organization.

The Section has already a membership which exceeds that of any Section or Centre of the Institution, either territorial or technical. There are definite qualifications for membership, and these make the Section in every way fit to be the hub of distribution technique and organization.

There is within our membership the great majority of those qualified to settle questions of policy, standardization, organization, and tariffs, and to advise on regulations and legislation and the major political and business problems connected with the distribution of electricity.

The questions which are unsettled in relation to distribution greatly exceed those which have been decided.

It must be remembered that on previous occasions when new legislation and regulations were being considered, there was no special Section of the Institution to deal with them. Who can say that the 1919 and 1926 Acts would have been quite as they are if there had been a Transmission Section?

The Chairman of the Section has a seat on the Council and it is provided that the Section Committee shall nominate a representative to serve upon each of the three principal committees of the Council.

As the Section is, or soon will be, fully linked up with the Committees of the Institution, it is for you to keep the Transmission Committee well representative of the Section.

One step already taken by the Committee is to keep open a date this session for a discussion of "Troubles," at which, it is hoped, members will ventilate any difficult matter, be it technical or in relation to regulations, or wayleaves, or the operation of the grid.

It is a matter of great pleasure to me to record that our President is an active Member of the Committee. We have also members nominated by the Electricity Commissioners, the Central Electricity Board, and the Post Office, so that your Committee is in a position to put forward, through the proper channel, any representations which may be necessary or useful.

A MAJOR ISSUE

There is a clear-cut issue between large-scale generation plus transmission and distribution of power, and manufacture by each individual for his own requirements—the very antithesis of the slogans "At the touch of a switch" or "At your finger tips."

Those of us who can remember the latter end of last century have recollections of seeing in almost every factory a steam boiler and engine, using anything up to 20 lb. of coal per b.h.p.-hour, usually befouling the atmosphere. Alternatively, there was a noisy gas engine. Electricity, whether in the home or factory, was a luxury for those rich enough to have an engine, dynamo, and accumulators, and a man or men to look after them.

Fortunately, power in the form of electricity can be generated on a large scale at a very low cost, lower than anyone can generate it on a small scale, because whatever means exist or are devised in the future for producing power, they will work for the power manufacturer at least as well as for anyone else. There is also a natural law that every type of engine or machine is cheaper in first cost per horse-power, and also more economical, in large than in small sizes.

The whole question of steam versus oil or gas would be revived by the production of the gas or oil turbine, if oil or gas could be produced at a price to compete, via its turbine, with coal and steam; but while this might produce a change in the working medium for super-stations it is not likely to affect the question of large units and transmission versus the small isolated power unit.

In a lecture on "The Economics of the Grid" by our President about a year ago, the comparison of costs of the grid (turbine station cost loaded with transmission) with separate power generation by Diesel engines, was given as shown in Fig. 1.

Substantially, these curves, prepared for the purpose of countering the claims of Diesel salesmen amongst our prospective power consumers, can be applied equally to destroy the case of the present-day advocates of small-scale local generation for distribution. These consoling thoughts indicate that large-scale generation and transmission of electricity will continue and increase.

For the immediate future, at any rate, we have the grid, and we can justify it on the score of economy as well as of convenience.

The achievement of the Central Electricity Board in producing bulk supplies at a cost of under £3 10s. per

kW, plus 0·20d. per kWh on a 10-year tariff, delivered at the required voltage at the centres of distribution, using probably too many power stations, some of them admittedly out of date and most of them passing from the second to the third class, is one which merits more praise than it receives.

The cost of the grid, including capital and operating charges, is of the order of 0·035d. per kWh. This very moderate cost is often forgotten by those who express doubt as to the success of the grid scheme. It would be interesting to know what the tariff would have been if new plant with 50 000-kW sets could have been adopted. This position will be approached in the tenth year of operation, by the gradual writing-off of the older and therefore smaller units in selected stations, as their age reaches the loan period on the Commissioners' scale.

SUGGESTED FIRST STEPS TO UNIFORM TARIFFS

(1) Having in view the attention being given to uniform tariffs, the decentralization of the grid tariff may be mentioned as a backward step, having regard to its recent origin. Each of the areas has a tariff on the same basis, but the prices are just a little different—enough to make it difficult to ask distributors to make some sacrifices to secure uniformity.

The same revenue would be obtained by the Central Electricity Board, and no one would be noticeably the worse if the average were charged all over the country.

(2) Again, there is the anomaly of "on charges" for transmission to certain unlucky areas, omitted from the grid layout, while other lucky ones have equally long mains provided free. While this is explainable, it is an example to the distributor to impose "on charges" to those he left out of his main layout.

(3) Also, there is the anomaly of the pre-1926 bulk contracts. Under Section 12 those who pioneered in shutting down their small stations and taking bulk supplies are left unassisted. Because costs were higher 9 or more years ago than a year ago, such undertakers often pay 25 to 75 per cent more than they would have done if they had retained their old plant and declined to take a bulk supply until after 1926. It is suggested that the Government might reasonably authorize the Central Electricity Board to take over these contracts until their expiry as "key money" or "in going," and make the tariff available to these, the oldest of the bulk-supply customers.

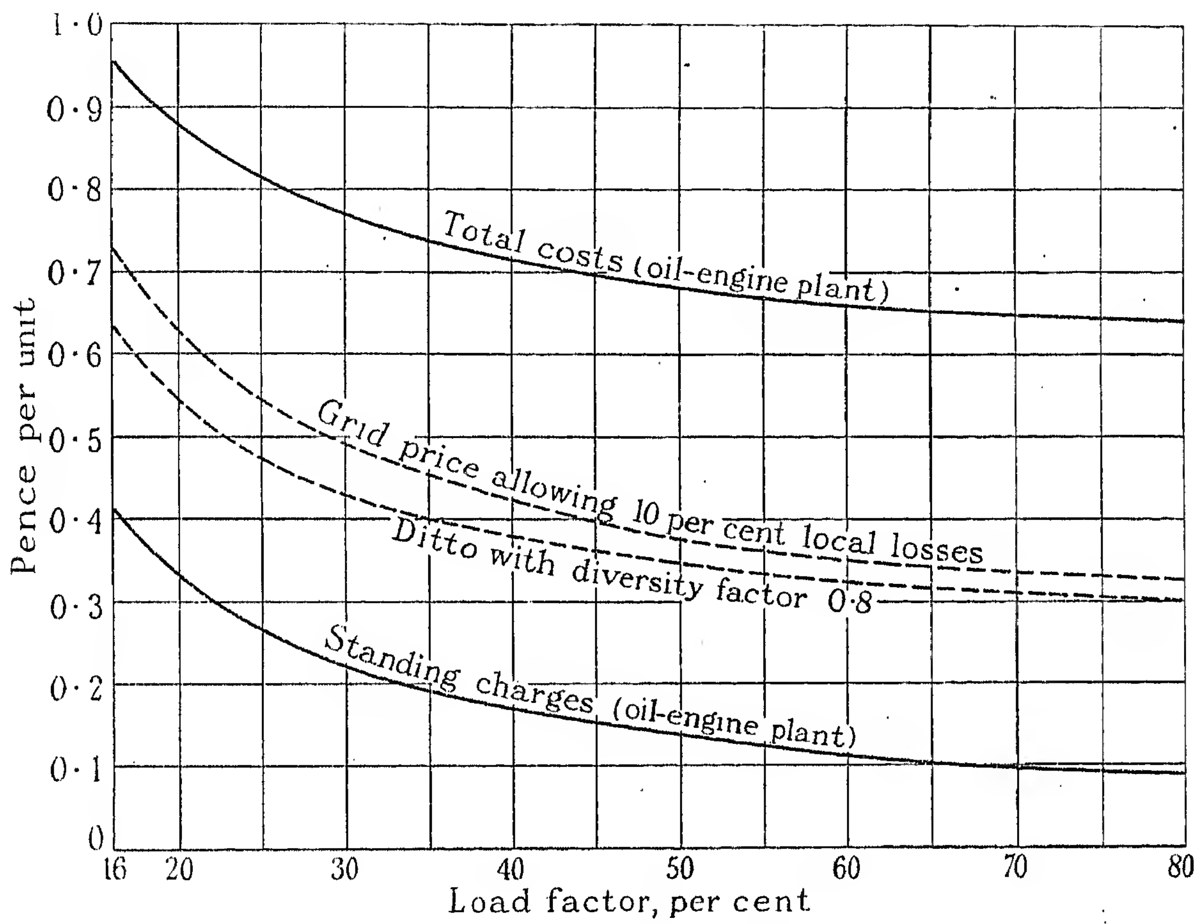

Fig. 1.—Comparative costs of oil-engine plant and grid price.

The loss, if any, involved in removing these anomalies would be very little compared with the impetus which would be given to uniform retail prices by uniform wholesale prices.

A SHORT REVIEW OF RURAL DEVELOPMENT AND SOME INDICATION AS TO THE MEANS FOR REDUCING COSTS

The ideal at which we must aim is a uniform price in town and country, not because the latter should be subsidized heavily by the former, but because overhead construction may be so reduced in cost that the overhead rural distribution cost per unit can be the same as the town underground cost.

A few pioneers had a conviction that this uniformity in distribution cost in town and country could be approached if regulations were eased and obstructions

of various kinds were removed. They proceeded first to work singly, and later to organize the Overhead Lines Association, to achieve this much desired object. It must be realized that in 1920 the Regulations were "impossible," and the Post Office autocratic and expensive, while the railways appeared to be anxious to make money out of line crossings. Many concessions have been obtained as a result of prolonged agitation, but the Regulations still unnecessarily hinder ultra-rural development, while the Post Office and the railways are still much too expensive in their ideas.

It has been possible and safe during this period of reduction in requirements to work always upon the limit of existing Regulations, in the certain knowledge that what was being queried as being on the outside edge of legality would be well within the pale of respectability after the next revision.

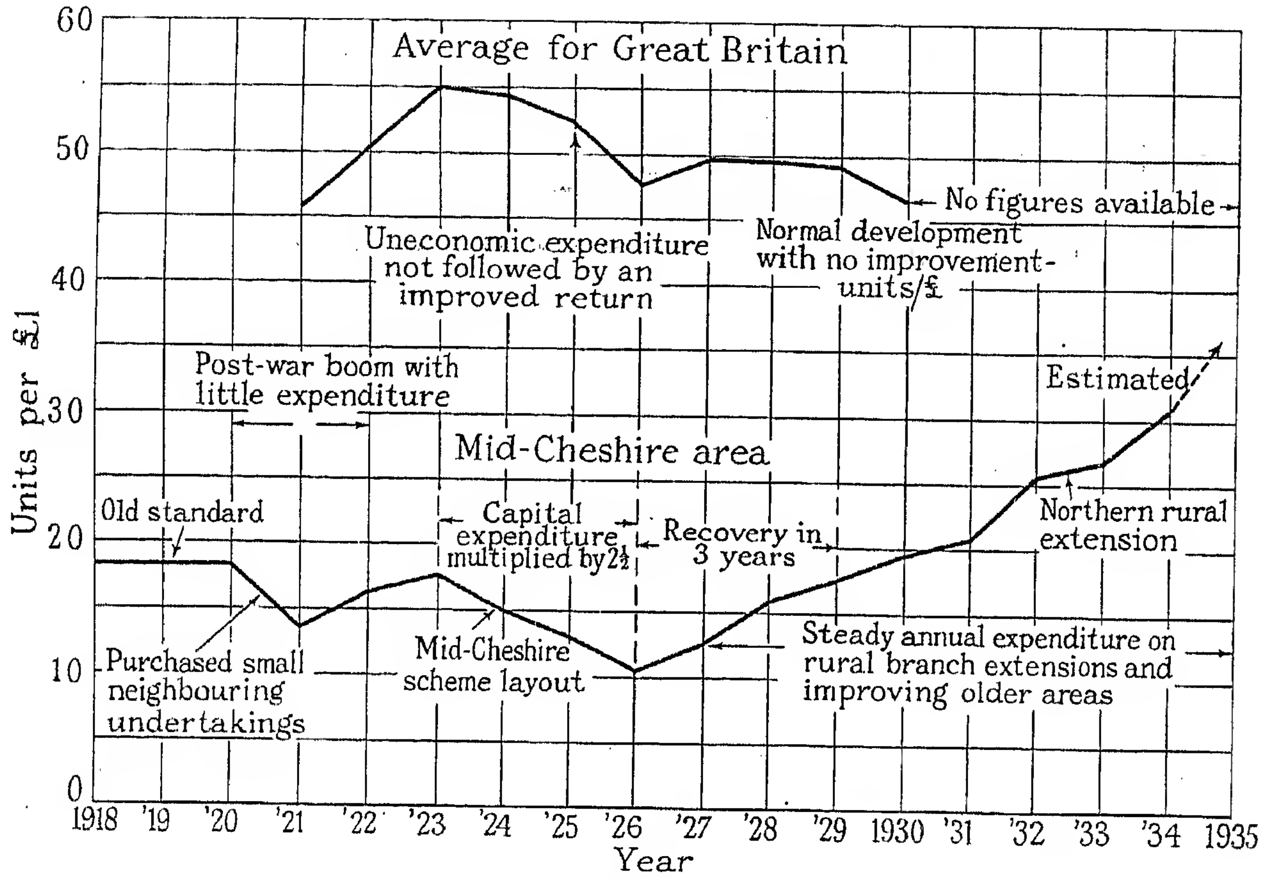

Fig. 2.—Units per £ of distribution capital.

It is not everyone, however, who has the enthusiasm to look upon this question of cost reduction as a hobby; it is only those pioneers who have done so who have escaped heavy over-capitalization on overhead work.

Another step towards cheap rural supply is the adoption of single-phase high-voltage, and the rejection of 4-wire low-voltage, distribution in the smaller villages and farming districts. The former system can cost under £200 per mile and the voltage regulation is good. The latter must cost over £400 per mile, while the regulation provided is very poor. Given single-phase cheap lines, single-phase transformers, and single-pole insulation, switching, and fusing, the serious problem of capital cost is capable of solution. This economy has been obtained by the Mid-Cheshire Co. by the unusual, if not unique, expedient of earthing one phase, instead of the neutral, of branches from the 33-kV main layout.

The Mid-Cheshire Co. has planned to provide a reasonably cheap and abundant supply in all parts of its area of 160 square miles, by:—

(1) A 33-kV main layout with pin insulators on "A" poles, interconnecting the four small towns and the largest villages *en route*.

(2) 6·6-kV 3-phase sub-mains, passing near the larger villages, one phase line earthed and two "live." This reduces the cost of insulation and needs only single-pole switch-fuses for single-phase, and double-pole switch-fuses for 3-phase tappings.

(3) 6·6-kV single-phase spurs to small villages and on to the remoter farm areas with single-pole high-voltage insulation and fusing.

(4) A general absence of expensive 4-wire distribution except in the few large and compact villages.

(5) A policy of hired wiring, cookers, water heaters, and wash boilers, etc., and hire-purchase of larger special appliances. A good central showroom and an active contracting department.

(6) Maintaining high flat rates. We have obtained 95 per cent of our domestic and farm load on a 2-part tariff with a low unit charge, which encourages successive additions of extra apparatus, even in the rural areas.

By taking all the steps indicated, the Mid-Cheshire Co. has been able to develop its area economically on a uniform tariff in town and country. The few large single-phase motors on the branch rural lines have cost 50 per cent more than 3-phase motors would have done, but we have been able to compensate their owners for that cost by lower charges than would have been possible if 3-phase motors had to be provided everywhere. Electric cookers and water heaters are commonly used, while a new "off peak" field is opening for sterilizers for Grade "A" milk. We can supply these, even on "tail ends," with the high-voltage system, but few

having low-voltage 4-wire mains can cope with such heavy heating and cooking loads, either in small villages or in the farming areas.

As an indication of the financial soundness of the above policy, I give in Fig. 2 the Kennedy " Distribution efficiency " curve of units sold per £ of distribution capital for the Mid-Cheshire undertaking during the last 15 years,* also the average curve from the paper by Mr. Kennedy and Miss Noakes.† The Mid-Cheshire curve shows the development of the area upon the lines I have advocated, in terms of units per £. The curve shows the very low capital efficiency of 1918–20 in the central town and suburban area.

It will be noted that the " efficiency " fell still further when the Mid-Cheshire layout expenditure was incurred, but thereafter it rose continuously, despite continued expansion of rural distribution, to a figure approaching the average, notwithstanding the scattered nature of the extension area.

It should be very easy for the late comers, who have avoided the 1919 to 1929 decade of expensive overhead construction, to deal with rural areas on an economic basis if they will only cease to copy in the country the system of the small town, viz. 4-wire low-voltage distribution, which will not deal with the prospective rural demand on an economic basis in the near future.

At present there are two high voltages in common use, 6·6 kV on the older systems in which town feeders have been extended into the country, and 11 kV, which may be called the standard rural pressure. There are a few cases where 33 kV has been used for main layout in the larger areas, combined with 6·6 kV or 11 kV as the secondary voltage for district developments. It is inevitable that many areas will soon need 33-kV mains superimposed upon the 6·6-kV or 11-kV mains to cope with the large rural load which will follow progressive reductions in charges.

UNDERGROUND DEVELOPMENTS

A few words on the city problem may not be out of place. While rural areas *must* have a high-voltage supply, because low-voltage mains have to be too large and expensive to be economic, owing to drop of voltage, the cities have come into a zone of experience which encourages high-voltage distribution. Low-voltage distributors have to be unpractically large or inconveniently numerous in parallel to deal with the multi-story buildings using electricity for light, power, and heat, on a large scale. Substations, in fact, are indicated in each block of buildings, so that low-voltage distributors are doomed to disappear from the streets in cities as in the rural areas. This is, curiously, a reversion to the pre-1890 house-to-house system of the late Robert Hammond. This process should be a great relief to the city surveyor, and a mine of wealth to the makers of transformers and those " in, out, and tap " high-voltage switching sets at about £120. The existing larger substations then must be stepped up a stage. Instead of being 6·6 kV/400 volts, they will be more and more 33 kV/6·6 kV. The outgoing mains will be 6·6 kV or 11 kV in rings leading to the " in and out " gear situated in each block of buildings. The existing substation low-voltage switchgear may be split up and moved to the larger blocks, if the gear is good and the engineer is of an economical turn of mind, as he should be.

Some of this work has been carried out quietly in our larger cities, and it requires a little imagination to see a development of this scheme suitable for the suburbs.

CHEAPER UNDERGROUND CABLES

It will be desirable to consider whether anything substantial can be done in the direction of reducing the cost of 11-kV cables to make them competitive for rural work.

It has to be admitted that there are reasons for believing that the existing standards of high-voltage cable insulation are too high. Without encroaching upon the field of the expert, it is clear from papers read before this Section last session that up to 20 kV (delta) insulation is in a happy condition, none of the " silent discharge " troubles met with at higher voltages appear, and no 11-kV failures seem to be due to breakdown of insulation. In other words, we could do with less radial thickness by adopting voluntarily some of the simpler and cheaper precautions for 11 kV which have been necessary for 20 kV and over.

Again, improvements have been made in lead-covering plant, so that, perhaps, there may be reduced lead thickness. There is, however, a limit to this development, because of the liability of lead to crumple on bends when it is thin in relation to the strength of the cable. This is already recognized in the increased radial thickness allowed for the larger diameters of cable.

It is not to be doubted that a perfectly good, unarmoured, lead-covered 11-kV cable could be made at a price 20 per cent less than that for a cable complying with the current British Standard specification, and with little, if any, reduction in reliability.

Fig. 3 shows the Cable Research rural cable. The saving in the 0·06 sq. in. size of 3-phase 11-kV cable amounts to about £75 per mile.

Recent improvements in interlocking tile covers make it possible to omit armouring for cables laid in verges, although it must be remembered that water mains are being extended into many rural areas, and there is some risk of damage to cables by workmen.

The saving which can be effected by omitting armouring is about £50 per mile, but this applies to both types of cable.

The net saving of £75 by the new construction is very acceptable, and in border-line cases would be very important.

The comparison between the overhead and underground systems for 11 kV along grass verges of country roads, where the normal cover cannot be departed from, is substantially as given below for 0·05 sq. in. cable:—

Overhead	£350 per mile with double suspension.
Underground (normal) ..	£675.
" H " (screened) cable ..	£600.

Across fields the Comissioners will accept a 2-ft. depth, and the protecting cover may be omitted. This reduces the cost of underground cable and laying by

* Further investigation shows that by omitting " Transmission " and other outlay not clearly " Distribution " the Mid-Cheshire curve is raised by approximately 30 per cent. The 1931 figure is 39 units per £.

† *Journal I.E.E.*, 1933, vol. 73, p. 97.

about £105 per mile, but from this must be deducted the rather heavy extra and unknown claims for damage and loss of manure, etc. One may say this would not be less than £25 per mile, so that £80 per mile is the net figure.

The overhead line, however, will now cost about £300—single suspension—bringing the comparison to:—

Overhead, £300; underground (normal), £595; underground screened, £520.

This is a distinct advance and will be very helpful in cases where wayleaves for straight overhead lines cannot be obtained and overhead construction is more

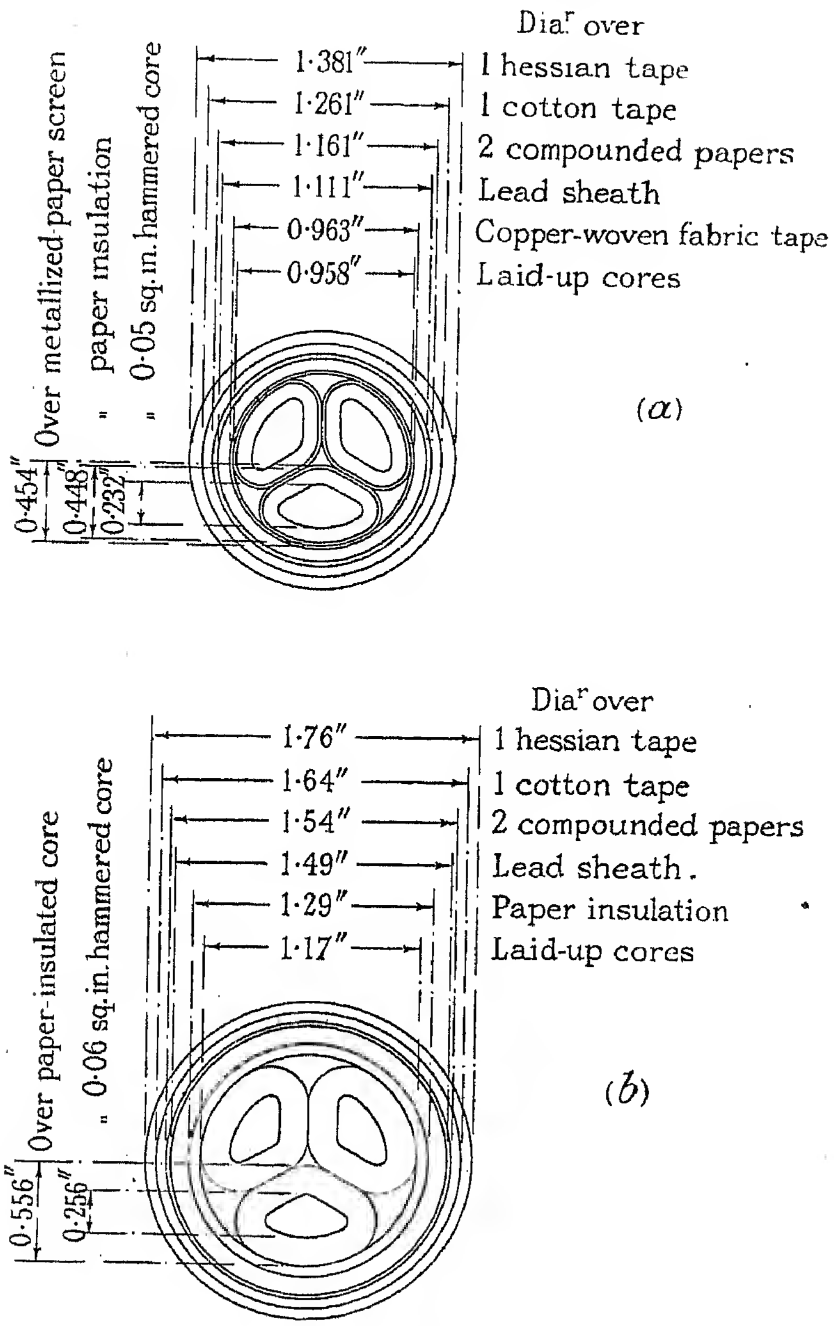

Fig. 3

(a) 0·05 sq. in. rural 11-kV screened cable.
(b) 0·06 sq. in. 11-kV belted cable to Table 10—B.S.S. No. 7.

costly, but it does not bring cable costs down sufficiently to meet our needs for cheaper construction.

There has been an idea that mechanical laying machines will greatly reduce excavation costs, especially across country. The wide track injured by these machines, however, involves heavy compensation. The difficulties of access to different portions along a route, the obstructions due to hedges and ditches in districts where small fields abound, and to stones and boulders, restrict the scope of these machines in this country more than is generally realized.

While there is a general desire to avoid overhead work on grounds of "amenities," there is no reason why electricity supply should be the only public utility expected to waste capital to keep up the Victorian standard of appearances. Overhead lines have a beauty of their own, which at least equals that of railway bridges. It has to be admitted also that the publicity effected by overhead work has a real value to the industry. While we exhibit our lines and outdoor substations as an outward and visible sign of electrical development, other industries have gas-holders and ugly poster boards. One has only to travel by train to see that these posters are far more disfiguring than the grid and other power lines which are seen from carriage windows. We users of overhead lines may be thankful that we are saved both the expense and the odium of extensive poster advertisement, especially as objection to lines evaporates when the public becomes used to their style of beauty.

There is a place for everything, and it is our duty to put everything in its place—underground in the towns, and overhead in the country.

Do we realize the great increase in domestic load which is developing in town and country? In order to bring this before you, I give, in Table 1, extracts from the monthly-connections report of the Mid-Cheshire undertaking for September in each of the years 1932–35 inclusive.

Table 1

KILOWATTS CONNECTED

Year	Lighting	Space-heating	Cooking and water heating	Total heating and cooking	Total
1932	38	Not separated		97	138·25
1933	28	Not separated		73	105·76
1934	41	49·25	391	441	563·01
1935	45	66	468	579	595·725

This change of aspect in this short time is symptomatic, as it relates to an area which is not by any means wealthy or inclined to "all electric" houses.

Such changes in local load, although they will not produce corresponding increases on the high-voltage system or upon the bulk-supply maximum-demand meter, must have the effect of rendering present-day ideas of low-voltage distribution obsolete in a few years.

EARTHING

One of the most difficult problems in connection with transmission and distribution is that of earthing, and no review of distribution technique is complete without a reference to it.

It is well known that in certain soils, and in rock, the resistance of earth plates or tubes may be 3 000 ohms or even more. Such earth resistances defeat the object of the various regulations, which specify earthing in order to produce safety.

The limiting value of an earth connection at the source is that which will allow sufficient current to flow from

a line fault to earth to operate whatever protective device is employed to disconnect the faulty circuit. Obviously, the resistance of the "fault" is in series with that of the earth plate, so that in bad-earth zones there is a double handicap.

If one takes the case of a high-voltage line which breaks and comes into contact with the ground, or an earthing guard which has a high earth resistance, there is a potential gradient in the vicinity which may be dangerous to life. Fortunately, a man does not bridge more than 3 ft. as a maximum, and in practice 2 ft. is the normal stride, but cattle normally bridge 4 ft.; moreover, they are far more sensitive to shock than men. This is due, no doubt, to the construction of their hooves, and to the high pressure (in lb. per sq. in.) upon them which causes them to sink into damp or wet soil. The fact is that a potential gradient of 30 volts per yard may be fatal to cattle.

Fig. 4 shows the distribution of potential produced by

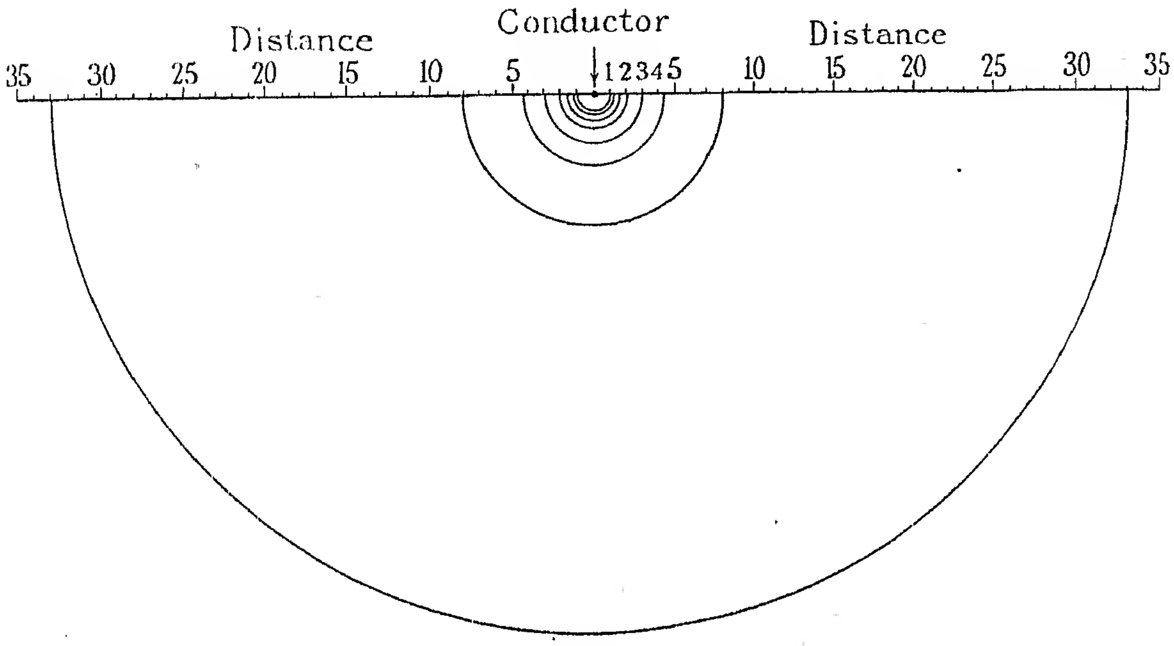

Fig. 4

a live wire on the ground, while Figs. 5 and 6 show potential gradients in the vicinity of an earth plate, where a cow was killed.

It will be noted that the higher the line voltage the less the importance of low earth resistance, provided momentary gradients are allowable. At 6 000 volts to earth (say on an 11 000-volt circuit) only 100 amperes will be passed if the sum of the resistances of earth plate, line, and leak, is 60 ohms. 30 ohms is thus on the verge of acceptability for a source-earth plate on a branch fused at 30 amperes.

The wisdom of the Electricity Commissioners' rule that where continuous earth wires are used they shall have 4 earth plates to the mile, is obvious, as it deals with insulator faults by providing multiple earthing for each insulator pin. Also, a rather high-resistance source-earth can be improved by connection to the earth wire. It is not obvious why individual pole earthing, i.e. without an earth wire, is used so widely and indiscriminately.

Numerous experiments are being carried out to deal with bad earthing areas. The use of salt in various ways is a natural and cheap method if it can be made effective. While one can use salt at the earth plate, however, unfortunately the fault resistance is out of control.

However difficult it may be to secure a suitable earth for the source of a high-voltage line, it is much more difficult in the case of low voltage, because the earth-plate resistance must be low also. Thus, 10 ohms is useless for the source-earth of a 230-volt system, however small, because, assuming the fault to be 10 ohms also, the leakage current will be $230/20 = 11 \cdot 5$ amperes, which will not melt even a small consumer's main fuse.

The I.E.E. Wiring Regulations specify 1 ohm as the maximum which can be allowed for consumers' earth connections for the casings of wiring and apparatus, unless an earth-leakage trip is installed.

It is not compulsory to obtain such a low earth resistance at the source, as the purpose is not quite the same. The system conductors are not exposed to being touched, whereas casings are handled regularly by the user. However, the resistance of the source-earth must be low enough to allow a sufficient fault current to pass to operate the main fuse of the largest consumer—say 50 amperes in rural areas.

If the fault resistance equals that of the source R, then $2R = 230/50 = 4 \cdot 6$ ohms, so that R at the source should be, say, 2 ohms as a maximum.

Fortunately, the Commissioners indicated the cure by multiple earthing when they specified 4 earth plates to the mile for earth wires on high-voltage systems.

If an average earth-plate resistance is 20 ohms in an area, then 20 of them will produce 1 ohm plus the average neutral-conductor resistance between them. Probably, also, some of the earth plates will be much better than the average. The provision of multiple system earths of moderate values between 2 and 20 ohms thus makes it unnecessary for the consumer to provide earth-leakage devices. The consumer can still provide his "earth" and use it for his casings and connect it to the system neutral, thus automatically improving the earthing of the whole system.

There should be a rapid change-over from single-earthed to multiple-earthed systems, once it is realized that the Commissioners will allow it on application, premises, especially in country places, are not conducive to continued efficiency of trip gears. The reason why small overload circuit breakers, which are very

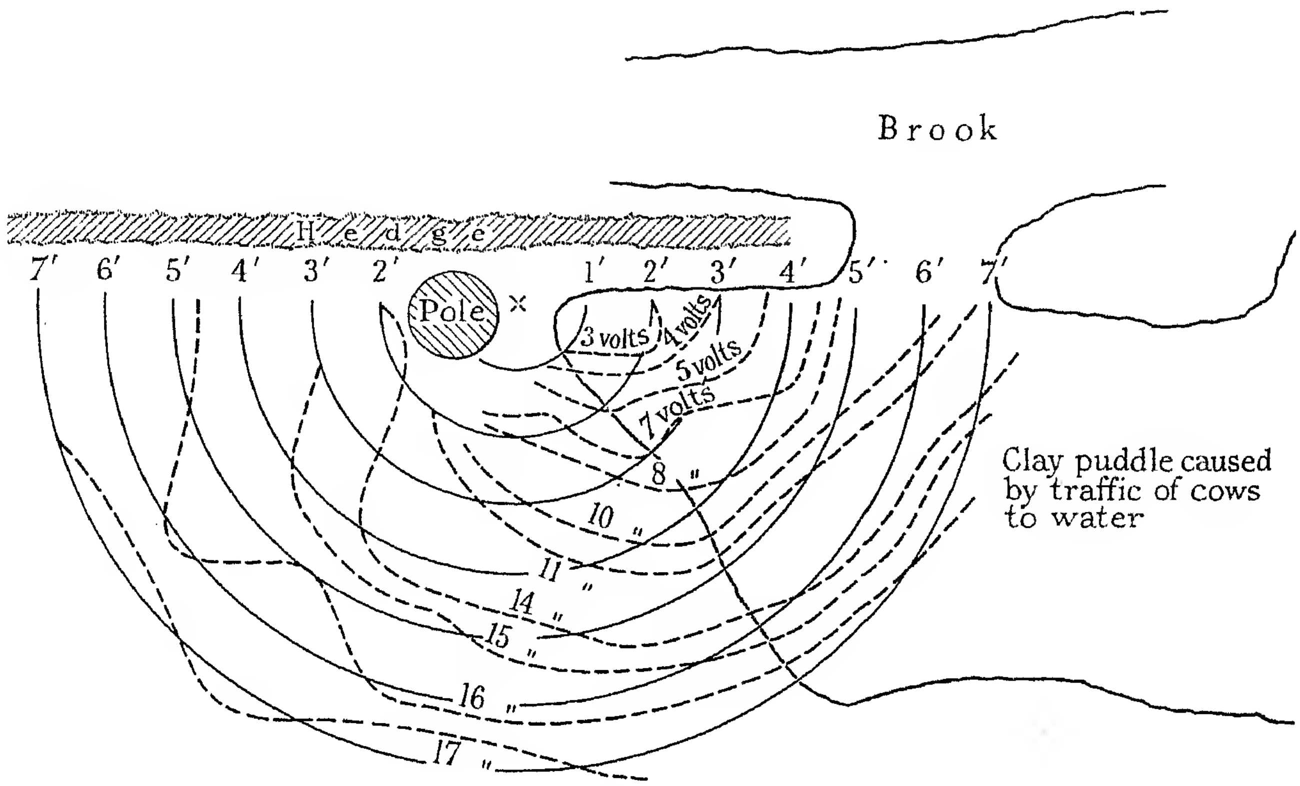

Fig. 5

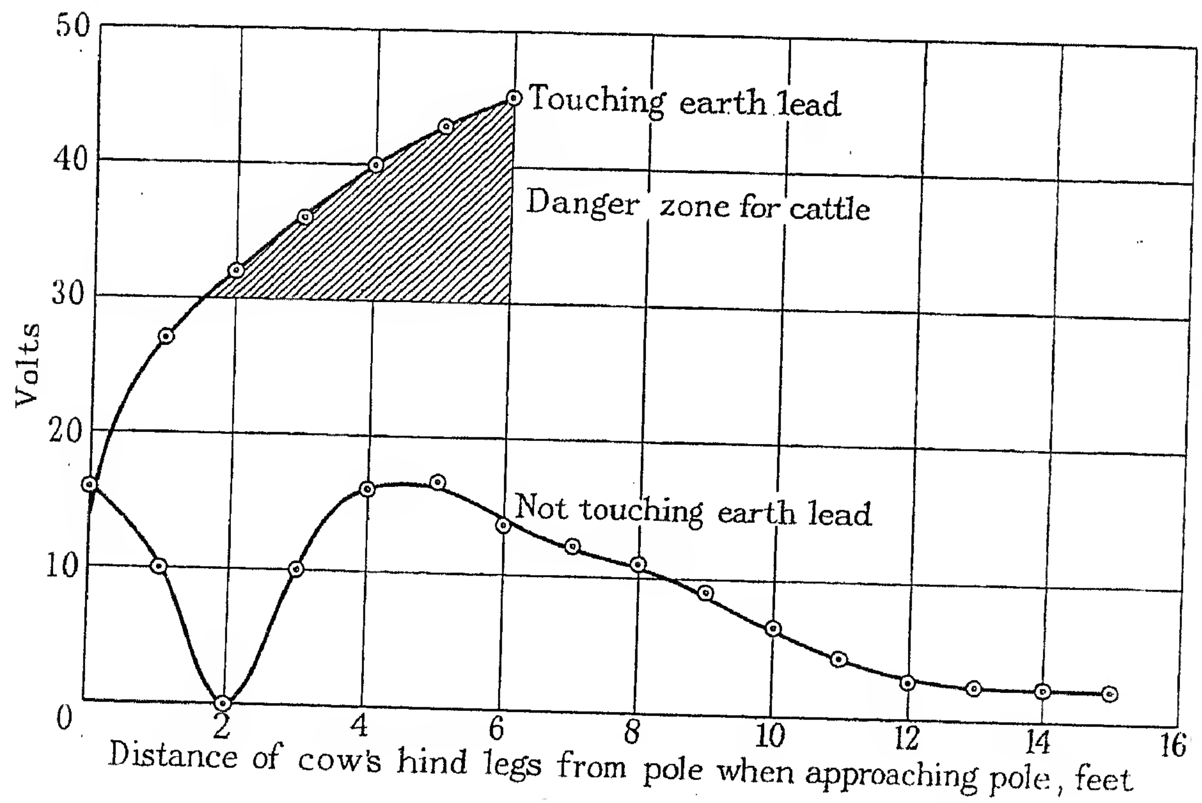

Fig. 6.—Earth tests Over Tabley, June, 1934.

Assuming cow is 4 ft. fore to hind legs.
Assuming cow is 6 ft. nose to hind legs.
Assuming cow is 2 ft. nose to fore legs.

NOTE:—With insulated earth lead, danger zone vanishes.

where cause can be shown and the Post Office cannot put forward any strong reason for refusal.

For very bad conditions, earth-leakage trips are a necessity. This is regrettable, not only on the ground of expense, but because the conditions on consumers' similar mechanically, have never made headway against fuses is that when fuse contacts are neglected the fuse eventually melts, while when a circuit breaker is neglected it eventually sticks. It is quite a different matter with important well-supervised installations.

THE DEFICIENCIES OF DISTRIBUTORS

The outstanding feature of the President's Address* was an insistence upon the fact that distribution costs have remained stationary for the last 10 years, while generation costs have been substantially reduced.

It was shown very clearly in Mr. Kennedy and Miss Noakes's 1933 paper† that the figure of "units sold per £ of capital cost of distribution" rose from 46 in 1921–22 to 55 in 1923–24 and thereafter fell to 46·8 again in 1930–31.

Cost of Distribution

Mr. Kennedy did not go into detail, but it may be assumed from his remarks that he maintains his standpoint of 1933, that there is some disgrace in the undoubted fact that not only the capital charges, but also the total cost of distribution, which is nearly all capital charges, is not showing any reduction in recent years.

This matter is of great importance, because upon it is being built up a demand that the system of organization of distribution shall be changed radically in the direction of providing fewer and larger undertakings, in the genuine belief that this will increase the capital efficiency and so reduce the cost of distribution. It may be interesting to examine the question of size in a new way, by seeing whether the average undertaking has been growing larger or smaller during the decade in which the distribution cost has been stationary.

The figures for Great Britain are given in Table 2.

Table 2

Year	Millions of units sold	Number of undertakings	Millions of units sold per undertaking
1921–22	3 122	473	6·6
1931–32	9 501	660	14·4

These figures show that although the output of the average undertaking has increased by 133 per cent in 10 years, the cost of distribution has remained stationary.

It will also be clear that the average area actually supplied in square miles must have increased by at least 100 per cent so that the experiment proposed, that of increasing the size of undertakings, has tried itself, without the result now expected being realized.

It will be fair to see if there has been any adverse influence tending to increase the cost of mains, such as cost of essential materials and labour.

The Cost of Materials

The cost of the essential materials employed in the manufacture of cables is given in Table 3 as on the 1st January in each year.

The cost of cables should therefore have decreased substantially in the period, and this should have helped largely to reduce distribution costs.

Sales of Units

It will be generally admitted that the sales effort, although not as high, even to-day, as is needed, has increased greatly in the decade. The Electrical Development Association has been operating, many showrooms have been opened, hire and hire-purchase schemes have extended very greatly, and uses other than lighting have increased enormously, so that here again we have a condition tending to increase the units per £ of distribution capital.

We have thus increased the size and sales effort, and decreased cable and labour costs, all presumably favourable movements, yet the units per £ of capital have remained stationary. There must be a very powerful adverse influence somewhere.

The Change in Density of Demand

It is very difficult to obtain a figure for this, because there are no statistics as to the actual areas served, compared with the nominal areas of undertakings. There is, however, a certainty that each undertaking, at its outset, deals with the "compulsory area," which is normally that in which there is most demand per mile of main. As the undertaking ages, it extends into the more thinly populated areas, or those in which the population may be high, but not of a type capable of using so much electricity per head, or per mile, as in the areas first served. Here we find the first possible reason for an increased or stationary cost of distribution.

Table 3

	Copper, per ton	Lead, per ton	Rubber (pure Para), per lb.	Labour index figure
	£	£	s. d.	
1921	83·00	26·0	1 0	110
1922	74·1	26·0	11¾	73
1923	72·00	28·0	1 1¼	67
1924	67·1	32·0	1 2¼	73
1925	71·15	45·0	1 7½	75
1926	66·00	37·0	3 6	75
1927	64·00	29·0	1 4½	73
1928	67·00	23·1	1 4¾	73
1929	77·15	23·1	10¾	72
1930	83·15	23·0	8¼	72
1931	49·1	16·1	5⅞	70
1932	50·00	16·1	4⅛	68
1933	36·00	12·5	4¾	65
1934	36·10	12·1	4⅜	63
1935	32·00	12·1	5	65

It is therefore reasonable to assume that with a given system and voltage the cost of distribution, whether expressed as units sold per £ of capital, or at per unit sold, will rise as the density of demand falls, and that this adverse factor has proved more powerful than all the helpful factors, viz. automatic increase in size (2½ to 1), the reduced cost of cables, the extension of uses in the home, and the increased energy in sales promotion, so that the net result is that there has been no reduction in the cost of distribution in the last 10 to 15 years.

Is the System Correct?

Can it be that the system judged in 1925 to be the best for distribution is no longer suitable, because we have

* See page 1.

† *Loc. cit.*

Table 4

COST PER MILE OF HIGH-VOLTAGE THREE-PHASE LINE

Voltage	Type of support	0·05 sq. in.		0·1 sq. in.		0·15 sq. in.		0·2 sq. in.	
		Overhead	Underground	Overhead	Underground	Overhead	Underground	Overhead	Underground
kV		£	£	£	£	£	£	£	£
11	Wood	320	—	425	—	550	—	670	—
	Steel	900	1 620	1 010	1 810	1 810	2 000	1 250	2 190
33	Wood	400	—	500	—	610	—	720	—
	Steel	1 050	3 300	1 170	3 590	1 300	3 890	1 430	4 130
66	Steel	Rarely used	None used	1 220	5 810	1 350	6 140	1 480	6 480
132	Steel	Rarely used	None used	1 320	9 350	1 440	10 000	1 560	10 700

COST PER MILE OF LOW-VOLTAGE DISTRIBUTION

Type of main	0·04 sq. in.		0·1 sq. in.		0·15 sq. in.	
	Overhead	Underground	Overhead	Underground	Overhead	Underground
	£	£	£	£	£	£
Two wire ..	240	497	288	627	336	752
Three wire ..	305	627	384	734	463	901
Four wire ..	466	752	626	856	786	1 084

passed into a new zone of demand? It is more than probable.

It is curious that prior to 1895 the 3-wire system was designed to extend the economic radius of distribution from about $\frac{1}{8}$ mile to $\frac{1}{2}$ mile by doubling the transmission pressure from 110 to 220 volts.

Again, the actual consumers' pressures were doubled in and after 1900 to 220 × 2, and 2 miles became the limit. The current density in distributors was, however, very low. The losses were confined to low-voltage feeders and rarely exceeded 10 per cent.

Those systems using high-voltage distribution with house transformers and street transformer boxes were discouraged because areas were small and high-voltage feeders were unnecessary. If distribution costs are to be reduced, it appears that, as we cannot increase the consumers' voltage above 230, we must reconsider a return to the high-voltage distribution system in a modified form.

There is another possible adverse influence.

Waste of Capital

Underground Work.

At the instigation of the Government, who desired relief works and granted financial "facilities" for them, very many miles of perfectly good d.c. 3-wire mains have been pulled up and replaced by new 4-core a.c. 3-phase mains. There has been, in fact, no sign of detailed inquiry by authority as to the economic justification for this move, as compared with the provision of new feeders, where distributors were overloaded. Money has been voted and loans have been sanctioned indiscriminately. To make a guess, one could suggest that the capital distribution accounts of most undertakings have been increased by 25 per cent to comply with these urgings by authority.

While the standardization of urban systems has been advanced, no one but the manufacturer has benefited in a definite financial manner, and over-capitalization has resulted, depressing the Kennedy curve.

CABLES VERSUS OVERHEAD LINES

The comparison in Table 4, carefully prepared 2 years ago for an article in *The Times*, will be of interest.

The figures are not at their lowest, but the comparisons will not be very different, for open country, if later developments are taken into account for both types. It is clear, therefore, that overhead construction should have preference in our efforts to reduce costs.

Overhead Development.

While it has been known that the cost of overhead work is very roughly half that of underground work, and that the cost of high-voltage overhead 3-phase lines is roughly two-thirds that of low-voltage 4-wire lines of much lower capacity, it may be pointed out that the policy, commencing with the Electric Lighting Act, 1882, has been to discourage it, both directly and by imposing restrictive regulations and procedure. Obviously, a reversal of this policy will reduce the cost of new work. There has been a tardy step-by-step easing of the Regulations, but it is no one's business to point out that details sent in for approval, either for overhead lines or for municipal loans, are too heavy, but only that they are too light. We need an economy officer at Savoy Court who will return applications with the note—"This is far stronger and more expensive than is required by the Regulations! Please cut the cost down or we will not approve." Also, he might say—"We consider underground work too expensive; please submit overhead alternatives."

In rural work, for every invention and device to secure a reduced cost there have been five or six to increase it.

Three-phase transformers, at the feet of poles, with expensive cable connections and boxes, have been used where single-phase transformers on the top of poles with bare connections, at half the total cost, would have been better.

Many hundreds of miles of low-voltage 0·1 sq. in. 4-wire overhead distribution mains have been erected

at £500 or more per mile, where 3·3-kV, 6·6-kV, or 11-kV, 2-wire 0·025 sq. in. mains at £250 per mile would have been ample.

Only a few have pursued the straight and narrow way to success in rural work—that of looking before they leaped and of searching for what they could leave out instead of seeing what extra they could put in.

Accessory Plant.

There has been, for both underground and overhead work, a piling-up of elaboration, an encouragement of expense in every direction—oil-filled busbar chambers with drop-down isolators for circuit breakers, where simple fuse gear or air-break isolators would have sufficed, elaborate instruments, elaborate buildings, indoor gear where outdoor would be much cheaper and safer; every day and in every way consultants, officials, and manufacturers, have been piling on expense. It will be remembered that Sir Felix Pole, at the Bournemouth I.M.E.A. Convention, as a super-manufacturer used our platform to suggest that we would do well to take a *long* view and *pay even more* for our electrical plant, so that presumably a portion of the extra profit could be devoted to research! Associations have been formed which have for their actual result the raising of prices to a standard which enables the unfit to survive.

Safety first has been pursued by the path of elaboration instead of by simplification.

It must be admitted that we have as an industry helped substantially to increase employment. Taking a long view, much of this work will not only have assisted the unemployed but will be indefinitely beneficial in the future—but this does not show on the statistics and will not appear for some years, by which time, perhaps, far-reaching decisions will have been taken without allowance for this factor.

With this orgy of spending on change-overs, producing little or no return, and of squandering on "rugged" construction, which word usually means something too heavy and expensive to be economic, of foolproofing everything at any cost, of complying with the demands of outside bodies for unnecessary protection, we have arrived at the point where our President is quite justified in making the odious comparison that while the cost of generation has been reduced enormously in the last decade, there has been no improvement in distribution cost.

We cannot go on spending an average of $\frac{3}{4}$d. per unit for delivering our product to the consumer.

The blame, if blame there be, cannot be placed entirely upon the undertakings; it rests also, and perhaps chiefly, upon those who have urged it and have pointed to the "prosperity of the industry" as a justification.

The Cure

The cure for this state of things is not, however, a scrapping of useful and efficient mains and gear, and standardization of what may well be the wrong system of distribution, requiring far too much insulation, copper, and lead, and iron buildings. It is to be found in still further sales efforts and facilities to consumers, but not less in a careful overhaul of one distribution technique, both in town and country, so that we can increase the carrying capacity of what we have by judicious amendments, and extend our areas of supply in both town and country on whatever system is able to produce the lowest cost per unit sold. Standardization of voltage and system, while desirable, is not nearly so important as economy in further capital outlay, which is essential.

It is to be remembered that our President's figure of merit is Units-sold/Capital-expenditure. To increase this ratio we must increase the numerator at a greater rate than the denominator.

Our watchword should therefore be "Energy and economy."

[The Address also contained a section dealing with mains in subsiding areas. This section has been omitted from the *Journal* as not being of sufficient interest to the majority of members, but any member who is interested in the subject can borrow a copy of the section from the Lending Library of the Institution.]

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE: CHAIRMAN'S ADDRESS

By OSCAR C. WAYGOOD, Member.

"THE ENGINEERING PROBLEM IN A MODERN STORE"

(ABSTRACT *of Address delivered at* LIVERPOOL, *14th October*, 1935.)

(1) Introduction

Taking the retail trade as a whole, the average annual consumption of each store is in the region of 300 000 units, which is the equivalent of the demand from approximately 200 householders using electricity for lighting and power purposes. The range of consumption is from 3 000 to 8 000 000 units per store. The modern store is thus of considerable interest to the electrical industry.

(2) Distribution

(a) Switchboard.

The type of main switchboard which lends itself best is the totally enclosed ironclad pattern consisting of oil circuit-breakers of the oil-pump type, with draw-out and isolating features, and protective devices. The principle employed in the oil-pump circuit breakers is that just before and during the time that the main contacts are opened the oil surrounding them is subjected to pressure in such a way that a stream of oil is directed round the parting contacts, thus ensuring a rapid and satisfactory rupture of the arc. Further, in the construction of the circuit breakers, a radial principle is employed affording low space factor and working clearances.

The incoming supply is passed through three transformers, the oil switches for these forming part of the main switchboard, the low-tension supply available being 400 volts, 3-phase, 50 cycles. The third of these transformers and oil switches is also equipped with busbar couplers allowing the one transformer to supply the whole of the board when the load is light, or alternatively either of two sections which may be selected by means of the busbar-coupler switches. The remaining units have capacities suited to control the supplies for heating, lighting, and power.

The most convenient form of sub-circuit control in connection with the various floors, is that of the combined switch and fuse board. Large boards of this type require to be well constructed, with a suitable main switch incorporated for isolation in cases of emergency. Double-pole circuit switches are desirable for safety purposes, and each switch is fed through a pair of fuses.

(b) Cables.

It has been found that the "drained" type of paper- or fibre-insulated cable adapts itself well to buildings of this nature. It is now possible to use sealing glands instead of the unsightly sealing-boxes usually associated with paper-insulated cables.

In considering the size of the cable for installation, the mechanical strength should be taken into account as well as the carrying capacity, since large installations often involve the drawing-in of two or three different sizes in one conduit.

Flexible cables should be used as sparingly as possible, and every endeavour made to standardize on two classes —cab-tyre-sheathed and an asbestos twin-twisted flexible for lighting points. Regarding the latter, there is no doubt that this type of cable is an improvement over the rubber class for internal use, and is to be highly recommended. Its fireproof qualities are obvious, but it is on the side of maintenance that it is found to excel, especially where the gasfilled lamp predominates.

For power distribution the appropriate cable is run to a convenient point and terminated at a busbar chamber. On this chamber, switch control units are mounted for motors in the vicinity. By allowing spare ways on this chamber, extensions are readily dealt with.

(3) Lighting

(a) General.

Light in the store is equivalent to power in industry. Units for light in a store are used in the normal hours of daylight at the same time as the manufacturer is using units to drive his motors, and yet there are still some supply authorities who attempt to differentiate between units used for light in a store and units used for power in factories, when discussing the question of tariffs.

The problem of lighting is of great importance and is interwoven to a very large extent in the general business of the store. The ideal form of lighting has yet to be found. The light should be of a varying quantity and quality to suit the different classes of merchandise. For instance, fabrics are not seen at their best under a white light of high intensity, neither are they seen to advantage in an even intensity of indirect light. It is only by a method of compromise that the best light-intensity value can be determined, so as to bring out all the many colours and qualities of the varied forms of fabrics and merchandise which are required to be stocked in order to meet the demands of the public. The store of the future may be designed to exclude all daylight, so that it will be necessary to introduce a character of lighting which will be true to daylight. It is an interesting problem, and one to which the lighting section of the industry should diligently apply its energies in order to produce the desired results.

In the design of fittings, attention should be given to

flexibility so far as ability to change the intensity of light quickly is concerned, and also that of maintenance, all of which are very important points. Whether the direct or indirect system should be adopted is a very controversial matter, and points could be advanced in favour of either. Both forms are very desirable for certain classes of merchandise; it would therefore appear that a fitting that will give either direct or indirect light or a mixture of both, is the most useful unit to adopt. Possibly the gaseous discharge-tube system may be the lines on which development in lighting will take effect.

(b) Display.

Display lighting for general display purposes is analogous to the "moth and the candle." At a remote period the art of display was entirely with the salesman; now the engineer can bring light in many novel and useful forms to his aid.

The distribution system must be planned to accommodate the many and varied demands, and this can only be done by a liberal supply of lighting points. Whilst this may prove costly in capital outlay, it tends to reduce maintenance costs.

(c) Emergency.

It is essential to provide an independent system of lighting for emergency purposes, so that, in the event of a breakdown of the normal supply, a limited supply of light is available for the convenience of the public and the staff. The installation of a battery system has many advantages over any other form. The immediate change-over to the emergency lighting at the critical moment is very important, and cannot be overemphasized, since seconds become of great value should there be a failure of supply.

The maximum load the battery will be called upon to supply for general purposes should be for the duration of 1 hour, as it may be anticipated that in the majority of cases the normal supply would be restored within that time.

The charged condition of the battery can be satisfactorily maintained by trickle-charging, whilst after a period of heavy discharge a quick charge can be given by a motor-generator or rectifier. A battery of 100-kW capacity is approximately the size required to give a good emergency light for an average modern large store having eight floors for merchandise and a sub-basement for general services and equipment.

The lighting may either take the form of an independent installation, or the main installation may be arranged so that a certain section of it comes under the control of the automatic change-over switches.

The emergency lights form part of the general lighting scheme during normal times, these circuits being wired back to a section allotted to the emergency lighting on the distribution board. The d.c. or battery feeds are connected to the bottom terminals, and the normal supply fed to the top terminals of the change-over switches. Whilst the normal supply is maintained, operating coils maintain the circuit, but an interruption of the normal supply releases the coils and the circuit is made by a gravity action of the change-over switches. The voltage of the battery is the same as that of the normal supply.

(d) Staff Location.

By installing coloured lights at selected points, and using a code, selected members of the staff can be quickly located. The lights are controlled from the telephone room. The request to find goes first to the operator, who, by telephone and lights, gets into touch with the person wanted.

(e) Fire Alarm.

The same system of lights as for staff location is used, and the code is related to positions on the various floors. If a fire breaks out, the person first noticing it presses the nearest fire-alarm push, which operates relays in the telephone room, which in turn automatically switch on the correct combination of lights for the particular location; but in order to prevent the colour combination being confused with that for staff location, the lights in the case of the fire alarm flicker. Immediately the fire is out the "All clear" is given to the operator, who clears the controls. It is interesting to note that the switch on the affected floor selects its own colour combination.

(f) Showcases.

Showcases or serving counters, when illuminated, play their part as a means of displaying merchandise. Owing to the skeleton construction of these, one is forced to adopt some form of strip lighting for the purpose of illumination, the most efficient being double-end strip-lamps in conjunction with reflectors. Architectural strip-lamps could often be adapted to this purpose, but at the present time the initial cost and subsequent maintenance makes their use prohibitive.

(g) Windows.

Window lighting calls for a system which will give even illumination of high intensity at all points of the window area, and the ideal system should give this intensity with the source of light as inconspicuous as possible. Direct light by means of suitable projecting reflectors and ordinary lamps still seems to be the best method of accomplishing this with an approximate loading of 100 watts per 15 in. of window length, having an average depth of 6 ft.; this system would give an intensity of 60 lumens.

There is no doubt that to starve a window of light is false economy, and it is unfortunate that the actual value of window lighting cannot be estimated from a selling point of view. Engineers are thus unable to justify the load they advocate.

In designing window-lighting schemes it is well to remember the heat dissipation of the lighting, particularly with regard to the effect upon wiring, and in certain schemes an asbestos flexible cable arranged in conduit will be found most suitable.

(4) Cooking

That a kitchen can be kept much cleaner by using electricity more extensively is not open to question. There may be some divergence of opinion over the advantages of electricity as regards maintenance costs, but in the main the tendency is to admit that running charges are reduced by electrical operation. These

arguments are not sufficient in themselves to justify the use of electricity, however, since it is the operating costs that will largely settle the issue. Gas engineers have still a strong hold on large kitchens, and they will maintain that hold until satisfaction can be guaranteed to the user of electrical appliances on the score of design, maintenance, and operating costs; particularly the last-mentioned. The problem of the kitchen is one that should be very seriously considered by the supply authorities and manufacturers, so that more definite information is made available.

I have been very interested, for the purpose of comparative figures on costs, in two large kitchens, one operated by gas and the other by electricity, and have come to the conclusion that providing electricity can be obtained at a rate per unit not exceeding one-twelfth of the cost per therm of gas, a saving will be shown in favour of electricity.

There is a general objection to the electric boiling-table, due in a large measure to the apparent lack of speed, which to a certain degree must be appreciated. Providing this is borne in mind in the designing stage, however, there is not the slightest reason why the electric boiling-table should not be equally as efficient as any other form of boiling-table. Fish and potato frying is another operation requiring special consideration if the general efficiency is to be maintained. Speed is of the utmost importance, and this can only be taken care of in the designing process: in my opinion the most suitable arrangement is the built-in pan solid with the framework, the elements being clamped rigidly to the base and having a comparative high loading over a given area. This arrangement I have had under observation for some time, and am quite satisfied that it has many advantages over what appears to be a standard design amongst manufacturers. For roasting and baking it is generally accepted that electricity is comparable with any other medium; in fact, there is none better.

In passing, I should like to say that in the design of the controlling switches the arrangement of the terminals is a matter to which greater attention should be given by the manufacturers, as it is undoubtedly the weakest point of the present standard equipment.

There are many prejudices to be overcome, and I feel that greater effort should be made to drive home to the public the many advantages that are obtainable from electric cooking. A brief description of an electric kitchen in Glasgow will now be given.

The boiling-table is 10 ft. long by 5 ft. wide, with twenty 8 in. × 8 in. plates and eight 16 in. × 8 in. plates, the total loading being 62 kW. Two 3-pan fish ranges are installed, with a loading of 10 kW per pan, making a total of 60 kW on the complete equipment. Two batteries of roasting-ovens, each battery consisting of two large and two small ovens, are included in the installation, the total loading being 56 kW. There is also one double-compartment griller with a total loading of 8 kW; the heating elements are at the top, and fitted to the grilling racks is a scissor attachment for raising and lowering.

In the bakery a double-deck oven, each deck measuring 8 ft. × 6 ft. and loaded to 48 kW, is installed; the average consumption per sq. ft. per week is 8 units. Watt-hour meters, incorporated as part of the oven, enable a close check to be kept on the consumption of electricity. To deal with smaller units, a double-deck oven with a loading of 13 kW is installed.

For the production of scones, etc., two hot-plates are used, each with a loading of 8 kW and a total surface area of 9 sq. ft. Fondants are prepared on a small hot-plate loaded to 2·5 kW, whilst proving is done in a double-compartment steel cubicle, each compartment containing a small hot-plate for generating the little steam required for this process. For dealing with tea, coffee, and milk, two café fountains are provided, each loaded to 17 kW and automatically controlled with the draw-off tap and thermostat. These are capable of meeting the heaviest demand. Toast is produced in a double-compartment toaster, with a total toasting area of approximately 3 sq. ft. and a loading of 10 kW.

The whole of the foregoing installation represents a maximum loading of 300 kW, as far as possible balanced on three phases. It may be assumed that the number of units used in the kitchen represents 20 per cent of the total consumption.

Many machines, too numerous to mention, are used in the kitchen in the preparation of foods; all are equipped with their separate motors and controlled by switchgear. The motor and switchgear should be built in as part of the equipment, in the interest of cleanliness. Too many manufacturers, whilst giving consideration to this so far as the motor is concerned, seem prone to forget the fact that switchgear should form an integral part, with the result that it is only too obvious that the starting gear was an afterthought. Where this is not so, efficiency is often sacrificed in the interests of economy.

(5) Power

(a) Lifts and Escalators.

To provide for the movement of vast crowds with ease and comfort about the modern store, is only possible by the introduction of lifts and escalators. Whilst lifts have been used for many years, escalators are a more recent introduction, and the tendency is to rely more and more on escalators as the main means of transport throughout the buildings, lifts being used only for express traffic from the lower to the topmost floors.

An escalator travelling at 90 ft. per min. is capable of dealing with 5 000 passengers per hour, whereas one lift of average size designed to travel at 450 ft. per min. would deal with 800 to 1 000 passengers per hour. The maintenance and running costs as between lifts and escalators are in the ratio of 2 : 1 in favour of escalators.

Prior to the year 1914, the prime mover employed in lifts was almost universally a direct-current motor, the voltage varying from district to district. There were private supplies of 100 volts, varying public supplies from 200 up to 500 volts, and occasionally railway track voltages of 600 volts. Alternating-current supplies were a rarity, and consequently very little development occurred of lifts connected direct to the alternating-current supply. In America, high-speed lift work was undertaken by the employment of a low-speed gearless machine, and speed regulation and stopping were obtained by means of resistance control. During the War

period, the United States endeavoured to obtain a standardization of supply at 400 volts, 3-phase, 60 cycles per sec.; and in England, since the War, progress has been towards standardization at 400 volts, 3-phase, 50 cycles per sec. Both in the United States and here, development has been progressing towards motors which could be connected direct to the line of the alternating-current supply, but full success cannot be said to have been achieved. When the difficulty was first encountered on lifts in the United States, especially with high-speed lift work, the advantages of a low-speed direct-current motor over any other type were so apparent that a compromise was effected, and the Ward–Leonard system of control was almost generally adopted. The use of a motor-generator set with each lift can only be regarded as a compromise to be employed until such time as a suitable motor is developed which can be connected direct to the line.

The problem is largely dependent on the load and speed (especially the speed) of the lift car, the difficulty being one of acceleration, retardation, and stopping, of the rotor. Up to a maximum speed of, say, 120 ft. per min., a satisfactory solution can be found by using a single-speed synchronous motor, preferably of the slip-ring type. This motor is connected through a step of resistances to the line, and accelerates to a synchronous speed. When disconnected, a mechanical brake is applied to the rotor shaft, and the lift car can be brought to rest with a reasonable degree of accuracy, but varying according to the load in the car. Above a speed of 120 ft. per min. a varying speed characteristic is desirable. The following are the various types of motors that have been, and are being, employed: (i) Brush-shifting a.c. commutator motors. (ii) Pole-changing motors. (iii) Single-speed motors with auxiliary motor and gear for low speeds. (iv) Single-speed motors with external means of control of brakes for slowing and stopping characteristics. (v) The tandem motor, which is a normal slip-ring machine with the addition of a double bar-wound rotor on the same shaft.

Where lifts are installed for floor-to-floor service, the most comfortable speed of travel is 300–350 ft. per min. In the case of goods lifts, 80 to 100 ft. per min. meets the average needs of the warehouse or factory. A geared a.c. motor system of drive meets these conditions, and also those for passenger lifts up to 300 ft. per min. For speeds of 300 ft. per min. and over, particularly for passenger service, the gearless machine with automatic levelling is preferable. A gearless machine consists of a low-speed shunt-wound motor and brake arranged on a bedplate, the driving shaft and brake drum being mounted on the armature shaft. Only two bearings are employed, and the absence of gearing and a thrust unit results in particularly smooth action and increased life of the apparatus, and, more important, reduced running costs.

Wherever possible, lift machines should be situated above the lift well, as with this arrangement the length of the lifting ropes is materially reduced and the load on the building is less. It will be realized that, except for high speeds with comparatively light loads, the pull on the ropes with machines below is considerably more than the weight of the machine. With the machine below, the load imposed overhead is all "live" load—generally doubled for impact—whilst with the machine above only the suspended load is "live" load.

The average unit consumption per car-mile is 10–12 for a gearless system and 18 for a straight a.c. geared system.

An escalator consists of the following principal parts: Running mechanism with steps. Track system for supporting the running mechanism. Balustrading and handrails. Machine for driving. Safety devices. Steel structure for supporting the escalator. Controlling apparatus. It is interesting to record that the British Standards Institution have a committee which is drafting a specification to deal very thoroughly with the technical side of escalator practice, but this specification will not be ready for some time—possibly 2 years. I am quite confident, however, that when the specification is available it will go a long way to making secure, for the users and architects, a very high standard and efficient installations.

(b) Display.

Movement is essential; without it the store would be dull and uninteresting. Many interesting and novel forms of movement have been introduced. In the main, it attracts, but in general the thought behind the development of the display is more particularly to demonstrate usefulness and robustness in construction.

(c) Cash.

In dealing with cash transactions the first essential is speed, and this can only be accomplished by mechanism of an automatic nature. The cash desk consists of a number of desks receiving and dispatching cash, and each is fed by a motor-driven belt travelling at an approximate speed of 400 ft. per min. The desk allows for carriers received from out-stations to be delivered on the upper belt, and then deflected down the chute to the cashier, who makes the change and places the carrier on a lower belt: it is then carried to the dispatcher, who in turn returns it through the appropriate tube to the sales assistant. In order to deal with the variations in traffic, carriers are diverted by means of a deflector so as to cut down the number of cashiers. For transporting duplicates of transactions larger tubes of special construction are used; these run between the cash desks and the check office.

The power plant usually consists of an air turbine directly coupled to a motor. It is more economical in dealing with a large installation to divide the equipment into a number of small units. Each turbine is driven by a motor with special automatic control gear, which cuts the units in or out according to the demand on the system. A vacuum of $2\frac{1}{4}$ in. of mercury should be maintained throughout the whole of the tube lines.

This arrangement gives a very flexible and economical system, and with the provision of an extra unit in excess of the maximum capacity required a stand-by is obtained to cope with the failure of any one unit. In order to distribute the load evenly over the units, a pre-selector switching arrangement is installed in the electrical circuits so that the sequence of operation may be changed from time to time.

(d) **Electric Ironing.**

The well-known iron with its trailing flexible connection to the plug point should be discouraged, as it is much too dangerous to be allowed in any organization. The alternative is a bank of electrically-controlled heating stands installed at a central point, and the irons plugged in and then withdrawn for use. An installation arranged on these lines tends to make the conditions for the staff more comfortable than any of the well-known methods, and, in particular, it gives a measure of safety as near the ideal as it is possible to obtain.

(e) **Clocks.**

For the convenience of the public it is necessary to install a correct time system with some form of master control. The synchronous clock has now reached a high standard of perfection, and, where the frequency of the supply is controlled, such a clock should serve the immediate needs. Where the electrical mains are made "dead" while the building is closed, some other system is necessary, and that of impulse secondary clocks controlled by a master clock is the most reliable.

In passing, it would be interesting to know why manufacturers still adhere to the system of series wiring for such installations. While this system has many advantages which are readily appreciated, from a maintenance point of view the parallel wiring system is to be preferred.

(f) **Hairdressing.**

Practically all manipulative apparatus for beauty treatment is applied electrically, and since the customer is brought so intimately into contact with the various appliances it is essential that great care should be taken in the layout of the installation and every form of protection embodied in order to safeguard against accidents of an electrical nature.

The average circuit loading is approximately 1 kW per cubicle, and the weekly consumption in a store equipped for complete beauty treatment is 1 300 units, which is 3 per cent of the total consumption.

(g) **Telephones.**

The G.P.O. during the last few years have made a very sincere endeavour to study the needs of the public, with the result that we have in this country a telephone system which, if there is one better, it must be a very good one. The criticism I would make of the system of charges is that perhaps some day the authorities will consider giving special terms to large users. At present, the man with the single telephone is charged at the same rate as the multiple user.

Private internal telephone installations are worthy of consideration, but the advantages can only be discussed in relation to the particular business transacted in the building.

A very excellent teleprinter service is now available by which messages can be transmitted in typewritten form from houses situated at remote points.

(6) Steam

Steam is used extensively for heating, and for various processes associated with cooking, production of hot water, etc. Oil-fired boilers are to be preferred to hand-fired coal boilers, but the cost of fuel oil at the moment prohibits their use, and one is forced to consider some of the many efficient automatic coal-firing equipments now available.

It may be of interest to compare the running costs of four plants, and in order to make the comparison as simple as possible the cost in gallons of water per penny is given: Oil-fired, Lancashire boiler, 3·4. Hand-fired coal, Lancashire boiler, 6·0. Hand-fired coke, Economic boiler, 7·0. Mechanically-fired coal, Lancashire boiler, 8·0. I appreciate that other well-known factors enter into this cost, but the figures are indicative of the present position.

(7) Refrigeration

In dealing with food, ice cream, display counters, and cooling in general, refrigeration plays an important part. Without it, it would be almost impossible to meet the varying demands. Temperatures ranging from −10° F. to 37° F. must be maintained throughout the day and night for perishable goods. These conditions can be met in regard to the higher temperatures by the installation of coolers in the form of brine tanks with submerged expansion coils, the brine acting as storage for the "cold." With the lower temperatures this arrangement is not advisable, inasmuch as the time element required is in excess of that of the direct cooling method, and, when dealing with a 12-hour working day, consideration must be given to the time taken to get the cold chambers to the required temperature.

Ammonia is regarded as the refrigerant to give maximum efficiency, but great care should be taken in the design of the plant and in its installation in order to guard against leaks and the attendant objections. It is for this reason that one is inclined to a refrigerant such as methyl chloride, which is very good for plants up to 7 h.p.

(8) Broadcasting

This is the very latest "limb" that may be added to an organization; such installations have caused considerable interest, and have greatly added to the amenities of the stores as shopping centres. It is possible with a broadcasting equipment to relay restaurant orchestras to the whole or a section of each store, or, when the orchestras are not playing, music can be relayed from gramophone records. Announcements may also be made through the microphone on any one or all floors to attract the attention of the public to special bargains, or to make inquiries regarding lost children or property.

Where a group operates in distant places, the equipments in each of the stores is identical and arranged so that when necessary the amplifiers in all stores in the various towns can be operated on the same programme from any store by means of interconnected G.P.O. telephone lines. The equipment may also be used for general talks to the staff.

(9) Fire Protection

The earliest recorded date upon which the idea of extinguishing fire through the medium of its own heat was employed is the year 1673, when a patent for a

device of this kind was granted to John Green. In 1806 an Englishman, John Carey, patented a perforated-pipe system controlled by weighted valves held closed by a cord, the burning of which automatically opened the valves. Records do not show that this system was adopted. In the year 1874 an American, Henry Parmelee, invented the first practical automatic sprinkler, which achieved considerable success in the United States; but it was not until the year 1882 that the first sprinkler installation was erected in England—in a cotton mill in Bolton. Many attempts were made to improve the Parmelee sprinkler, and in 1883 the now well-known Grinnell sprinkler made its appearance.

In buildings where the water in the pipes is likely to freeze, a dry pipe system is applied. The installation pipes are charged with air at a moderate pressure, and the water supplies are held back beyond the reach of freezing by a differential air valve.

The sprinkler heads are set at a melting temperature of 155° F., and the heads can be modified to suit special conditions.

(10) Ventilation

(a) General.

In the equipment of a store, efficient ventilation is of paramount importance. To give adequate ventilation it is necessary to provide a combined plenum and extraction system: the plenum system to supply fresh air, distributed at intervals throughout the room to be treated, and the extraction system arranged so that the vitiated air will be extracted at points remote from the air inlets. By this system the full scavenging effect of the fresh air is obtained, and the possibility of pockets of stagnant air is avoided.

It is essential that all fresh air admitted to the building should be properly filtered and free from atmospheric impurities. There are two types of filters most suitable for this purpose, as follows: (1) Oil-film or viscous filter. (2) Water spray air-washer. During winter months it is desirable to warm the air to a suitable temperature before distribution to the building, in order to prevent draughts and maintain a comfortable temperature.

In designing a combined plenum and extraction system for general ventilation, the extraction plant should be arranged to extract only about 75 per cent of the plenum volume in order to obtain a slight plenum in the room, which will tend to prevent the ingress of dust and fog, etc., from outside. In the case of lavatories, kitchens, or rooms where heat or fumes are generated, the plenum volume should be about 25 per cent less than the extraction volume, in order to prevent the heat and fumes from being forced out into other parts of the building.

The following air-changes per hour have been found suitable for general conditions of ventilation: Sales departments, 4 to 6. Private offices, 4 to 6. Cash-tube rooms and switchboard rooms, 10 to 15. Toilet rooms, 10 to 15. Kitchens, 30 to 40. Stock-rooms, parcels, receiving, and dispatch rooms, 4 to 6.

(b) Air-conditioning by Refrigeration.

This system of ventilation is very popular in America, but has not found favour in this country to any large extent, owing to the very high capital costs involved. It is very difficult to adapt this system to a building already in existence, since the efficiency depends in a large measure on the building being sealed.

(11) Merchandising

I have tried to interest the British Electrical Development Association in the greater use of the store for bringing home to the public a better knowledge of the use of electricity and of the equipment available. If the Association could concentrate their activities on one particular section at each period of the year, practically the whole of the country would be covered.

I also think that some steps should be taken on the vexed question of the earthing of domestic appliances. It is no use criticizing the retail trade for what they sell; the retailer can only deal in the markets furnished by the engineering trade, and if he fails it is entirely due to the bad example that has been set. At any rate, some set standard should be laid down, and all manufacturers forced to subscribe to it. This step is a very necessary one, in view of the increasing use that is being made of electrical domestic appliances.

(12) Conclusion

In conclusion, I often wonder whether we are making the best use of our many advantages, the greatest of which is the grid. The progress during the post-War years has been phenomenal: great strides have been made in lighting, but only on very set lines: cooking by electricity has only been tackled in a very half-hearted manner, and standardization is still a subject to dream about. There is not the slightest doubt that electricity is the best servant for man, and by its greater use the conditions of life both at home and outside will be improved to such an extent that more time will be available for man to enjoy the good things of life which Nature has provided.

The answer to the now classic question "What is electricity?" may still be in the minds of the gods, and they in their wisdom have allowed mortals to generate, control, and distribute to the service of mankind. I cannot call to mind, other than life itself, anything more wonderful than electricity. By its uses many great achievements have been made, and the whole outlook on life during the last 20 years has been re-fashioned. What of the future? It is a great trust. May the electrical engineers of the future never be able to say that we of this generation failed them.

NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By F. C. WINFIELD, M.ENG., Member.

(*Address delivered at* NEWCASTLE *14th October*, 1935.)

I propose to consider some of the features in the electric supply industry in this country which have struck me in reviewing the experience of the last 10 years.

The most outstanding change in the electric supply industry since 1925 is the increase in the voltage and capacity of our transmission networks, and it is of interest to consider what measure of success has met our efforts here, what problems still remain with us, and how well advances in other branches of the industry have been correlated with the advances in this branch.

Ten years ago the vast bulk of high-voltage transmission in this country was by underground cable at voltages up to 22 000. One or two 33-kV cable installations were being launched, and at least one experimental application was being made at 66 kV. To-day, largely owing to the operations of the Central Electricity Board, in addition to the large-scale introduction of underground cables at 66 000 and 132 000 volts, there exist several thousand circuit-miles of overhead-line transmission at 132 000 and lower voltages, which have brought many new problems.

Dealing with underground cables first, the early years of the decade revealed an astounding and quite unexpected failure in the apparently simple step in cable voltage from 22 000 to 33 000 volts. The step was taken carefully, and experimental installations were tried for a few years and appeared to be entirely satisfactory. The larger applications which followed were dismal failures. The old form of belted cable, satisfactory for voltages of 22 000 or less, proved quite unsatisfactory for 33-kV working, mainly because the dangerous voids produced by mechanical and thermal stresses were much more troublesome at the higher voltages. This was ultimately solved by a longer impregnation process and by the use of the Hochstadter sheath, which was designed to eliminate tangential stresses in the dielectric and to ensure symmetrical arrangements of insulation under radial stress and maintain these independently of any reasonable distortion of the cable.

The impetus given to cable research by these failures, besides doing much to develop understanding, had a still more important effect in producing the pressure oil-filled cable which, by making impregnation continuous in actual service, has effectively eliminated the problem of voids and permitted cable voltages to be raised to 66 kV, 132 kV, and even 220 kV. The success of this type of cable may be judged from the fact that, although the length of cable installed during the past 5 years is probably not less than 50 miles at 66 kV, and 30 miles at 132 kV, and rather more abroad, there has never been, to my knowledge, a single electrical failure on this type or on its associated joint boxes.

Some miles of another type of 66-kV cable, the high-pressure gas cable, which was invented by Dr. Hochstadter and introduced into this country by the late Dr. Bowden, have now been in commission for some 3 years, and other similar developments are in hand but are as yet still in the experimental stage. It is sufficient to note that these attack the problem of voids from a different angle, by applying a pressure to the cable of the order of 200 lb. per sq. in. and thus compressing any gases present to a point at which ionization does not occur.

The electric strength of oil-impregnated paper itself places an ultimate limit on the design of cables along present lines. Unless some improved medium is found, this limit is about 300 000 volts. Future research will, no doubt, be directed to overcoming this limitation and may react on lower-voltage cables.

Cable joints and sealing-ends are the weakest part of any cable system. The production of a cable joint effectively free from dependence on the jointer's skill is an outstanding requirement of the industry. The same may be said of the high-voltage bushing employed in metalclad switchgear and elsewhere. Failing this, or in addition, the development of a reliable means of detecting faulty joints both in the works and in the field would be a real aid to the reliability of electric supply.

The extensive use of overhead lines and outdoor switchgear at 132 kV for the Central Electricity Board was a new development in this country, although our manufacturers had some experience of this work abroad.

The practice of mechanical testing of the steel towers or pylons which was adopted at the outset has proved very sound, and we have been free from the tower failures experienced abroad. This indicates also that our national requirements for overhead lines, if worked to, produce a sound job.

For the line conductors the use of aluminium steel was almost imperative, and in some sections serious vibration troubles were experienced. The adoption of the Stockbridge damper after a series of trials on many types has, I think, eliminated this trouble.

Corrosion troubles have not been serious.

Fog caused trouble at first, but increased insulation has eased the difficulty and the application of new designs of anti-fog and anti-dirt insulators may be expected to give still further improvement.

Lightning has proved the most serious difficulty. This problem has not advanced greatly towards solution in the past 10 years, but the signs now are very much better. The old haphazard attack on this very abstruse problem is giving way to the method of statistical examination and recording, coupled with extensive

laboratory research and international collaboration, and I think it a reasonable prophecy that within the next 5 years lightning will be under practical control.

The overhead line is forced on us by the need to give electric supply cheaply, and its immunity from fog, dirt, and lightning troubles is still an urgent problem.

Some results from a recent statistical inquiry into lightning outages on 132-, 66-, and 33-kV lines in this country, although covering a period of 2 years only, are of considerable interest. These suggest that lightning outages per mile are inversely proportional to line voltages, and as the average line section length is roughly proportional to line voltage we get the interesting conclusion that lightning outages per line section are roughly independent of line voltage. The examination suggests that, on the average, we may expect one outage per line section every 5 years whatever the voltage of the line, within the limits given.

This statement must be accepted with caution, as it covers too short a period and, in any case, lightning is not evenly spread throughout the country but occurs in patches. Hence the actual conditions are much worse than the average figure would suggest. It is probable that lines of 250 kV and upwards will show considerable immunity from lightning failures, as there is evidence to suggest that the voltage of most lightning effects lies below the breakdown value of normal insulation for a 250-kV line.

Another particularly interesting indication of the investigation referred to was that it was possible in something like 85 per cent of the total outages recorded to return the line to service immediately, whilst, of the 85 per cent, about half only called for repair work afterwards. This indicates the value of auto-reclosing switchgear as one method of attack on the lightning problem and even other causes of overhead line outage. Unfortunately, auto-reclosing cannot yet be applied where questions of synchronism arise.

This leads me to the subject of high-speed switching and relaying.

When feeder systems mainly used underground cables, pilot and balanced forms of protection gave reliable and quick fault discrimination and isolation. With the advent of high-voltage overhead lines, however, economic considerations ruled out the general use of pilots and recourse was had to impedance and reactance protection new to our experience in this country. Subject to minor teething troubles, however, these have, so far, given excellent service, but their chief drawback lies in the time required to clear faults. With pilot protection we were accustomed to fault clearance in times of the order of ½ second. With the non-pilot protection this period may rise to 1½ seconds. This results in increased system disturbance and increased liability of extensive damage to lines and plant.

Notable developments are now taking place in the direction of high-speed switching and relaying, and if, as seems probable, new high-speed circuit breakers and relays can be obtained to give clearances of the order of 4 or 5 cycles, we may hope to take advantage largely of simple definite time intervals for discrimination and to reduce the maximum time of fault interruption in the worst case to, say, ⅓ second. Further still, it may become possible, by adding super-quick closing to our super-quick tripping, to ignore conditions of synchronism even and adopt auto-reclosing for all kinds of lines indiscriminately.

The effect of advances of these kinds on overhead-line work may be to reduce outages to a very small number and to achieve that most desirable end of making overhead lines as reliable as underground cables.

Passing to switchgear generally, the decade has seen the success of the metalclad type of switchgear originated by a firm in this area over 30 years ago. In the last few years the voltage of this type of switchgear has been successfully pushed up to 66 kV and 132 kV, thus keeping pace with its metalclad counterpart, the underground cable.

Perhaps the most noteworthy change in switchgear outlook which has taken place, however, is in reference to fault rating. Up to 5 years ago it is fair to say that almost all switchgear in this country and elsewhere possessed no true proven fault rating, and the design in respect to fault-interrupting capacity was mainly empirical and uncertain. In fact there was no true definition or understanding of fault-interrupting capacity, and in this sense the switchgear industry lagged seriously. In the last few years, however, no less than three testing stations have been started in this country and a considerable measure of international agreement has been achieved on definition of rating and methods of testing. That this was necessary is evidenced by the wholesale de-rating which has taken place of many types of existing switchgear.

The testing work which is being done is at last putting switch design on a scientific basis. Ten years ago practically the only form of arc-control device in use was the old form of explosion pot, which was frequently very erratic in operation. To-day most new high-power switchgear is fitted with arc-control devices, of which there are several forms. Correctly designed and applied there does not appear as yet to be much to choose between the several available forms, but one result of the testing experience which has been gained is to point to the extraordinary danger of simple extrapolation of data in producing new designs. It is not too much to say that at the present time complete reliance cannot be placed on any circuit breaker unless the type has been submitted to real tests.

In my view, one of the most important advances needed in this branch of engineering is the recognition of the imperative necessity of complete type testing of each new range of switchgear. The present tendency is to include fault testing only if called for by the buyer, and to charge heavily for it. In my view this policy is wrong. Fault interruption by a circuit breaker is its most important, its most difficult, and its most dangerous function, and I feel that it is a manufacturer's duty, now the means exist, to sell only proven types of gear rather than to leave the proof until some buyer insists and then saddle him with a personal charge which ought to be general to the range.

On the user's side, appreciation of the dangerous condition of many existing switchgear installations is leading to wholesale surveys of the position, which may

be expected to produce much modification and replacement of switchgear during the next few years.

Before leaving this subject, I should like to refer to tank strength and remote operation.

Any circuit breaker, no matter how well designed and constructed, may fail. For this reason I consider that, except in the very small sizes, remote operation is always desirable. Further, given failure from some fortuitous cause, a strong tank offers a second line of defence to arc-control devices and gives also a considerable assurance that, even if failure occurs, the fire will be largely restricted to the immediate vicinity of the circuit breaker.

Turning to the electric generator, the steam turbine remains our prime source of power. Two problems here require attention. With increasing capacity of units the time required for running up from cold is increasing greatly and is reducing the flexibility of use. This may militate severely against the use of large units. Secondly, it is difficult with present governing methods to ensure that, in times of electrical fault, turbines will not trip owing to overspeeding. Improved forms of governing are desirable to remove this difficulty. Subject to these two qualifications the art of turbine design is keeping pace very well with other branches of the industry.

It is apposite to digress here to refer to the activities of the Central Electricity Board. I need not detail the purposes of the Board, as these are already well known, but it is of interest to note that the reduction in capital expenditure on generating plant due to grid operation is estimated at about £10 000 000 to date, and that the efficiency of total generation has also increased considerably since its inception, indicating that the grid is beginning to fulfil the purpose for which it was laid down.

Some financial and commercial problems are proving slow of solution and, for economic reasons, obsolescence of non-selected stations must not be permitted to proceed too rapidly, but I imagine that the fruits of the grid scheme will be very evident in another 5 years.

It has been suggested that the grid has reduced the reliability of supply. I would remind you, however, that during the period I am covering there have been many mishaps with independent power stations, some of which have resulted in much longer interruptions to supply than has the most serious of the grid failures. It is true that interconnection may increase the area of any single disturbance, but it is equally true that it must ultimately give a better safeguard against long-time interruption than can be obtained from independent stations.

I would also remind you that the grid network, which is the most extensive in the world, was, largely as a contribution to unemployment, completed in something like 5 years. A completely new system of this type, with its new and unusual technical problems and a completely new operating organization, must inevitably suffer from teething troubles and, like any other organization, have to learn from its failures.

The number of serious teething troubles which have developed has been remarkably small. Already the bulk of these have been dealt with or provided for, whilst the remainder are well on the way to solution.

I wish to draw attention here to the change in power-station outlook which has taken place as a result of the grid.

The considerable interconnection pursued on the North-East Coast in past years raised the unit of transmission and generation to something like 20 000 kW. In the same way the activities of the Central Electricity Board, which were in no little degree modelled on the North-East Coast experience, have raised the unit of transmission in our thoughts to something like 50 000 kW, which is broadly the average capacity of a 132-kV overhead line and which is typical of the size of generator and switching unit that we now have to deal with in our major work.

Still further, the generator has now become more clearly identified with the transmission side than with the distribution side, and it is very desirable that this aspect should be clearly understood. Public electric supplies commenced with small combined generating stations and distribution centres with common busbars. The next stage saw bulk transmission to outlying distribution centres, but the generating station busbars remained and still remain the principal distribution centres.

There are many reasons, principally economic, why this arrangement becomes bad with the growth of size of our generating stations. For example, in our new generating stations and our grid transmission we are employing switchgear of a rupturing capacity of 1 500 000 kVA, and we are being forced still higher, whilst the size of generator and transmission unit to be controlled is of the order of 50 000 kW or more. Against this, in our 6-kV and 11-kV distribution systems the size of unit in our thoughts is more of the order of 5 000 kW or less, and switchgear of 1 500 000-kVA rupturing capacity is simply out of the question.

There are many other technical aspects of the problem which I have not time to touch on, but the point I wish to make is that the time has come when we must change our outlook and consider our generating stations more as belonging to the major transmission networks and dissociate them from direct connection with our distribution networks. The present association of generating plant with distribution centres is to-day costing many thousands of pounds.

For this reason and others, I feel that, except in special cases, all future generating stations will switch at 33 kV or above; and this brings me back to the generators. It is clear that, given switching at such voltages, it is preferable, other things being equal, that generation should be at the switching voltage, since this eliminates the step-up transformer and should result in simplification, lower capital costs, higher efficiency and, perhaps, reduced switching duty. The generator, however, has not yet caught up to the transmission system in the matter of voltage, and 132-kV generation has not yet arrived, and perhaps never will. However, the lag is not very great, since the same North-East Coast firm which made generation on present lines possible has in the past few years given further proof of its continued virility by the production of satisfactory 33-kV generators and is now being followed by other manufacturers. Further, this same firm is prepared to supply 66-kV generators if required.

It seems very unlikely, however, that commercial 132-kV generators will ever be produced unless some

new insulation makes its appearance. The gap here does not occasion any undue concern, as the transformer has kept pace in size and voltage with other power plant.

One important question occurs to me in respect to generation, and that is the dearth of suitable sites for large generating stations inland. Modern efficient generation requires large quantities of water for condenser cooling, and this factor is almost the principal one in determining suitable sites. In England, once we get away from tidal waters, there are very few sites suitable for large-scale power development.

The new generating plant authorized during the last year in this country totalled nearly 500 000 kW, and this figure is likely to increase in the future.

During the coming years, therefore, if the present outlook in design continues we are likely to look more and more to the coast line for sites for large power stations.

This may make necessary the transmission of large blocks of power from the coast to points 50 to 100 miles inland. If 220-kV lines do prove to be relatively immune from lightning troubles it is possible that this, or a similar voltage, may prove the most economical for this purpose. Practically this would not be wholly desirable, as, unfortunately for the purist in engineering, it is likely to prove increasingly difficult in a densely populated country like ours to send a line 40 or more miles without submitting to intermediate tapping. Given this, both for general reasons and for economy of tapping, it seems undesirable that a new voltage should be introduced and preferable that any new transmission should fit into the general 132-kV scheme which has proved very suitable for our loads and distances.

Further, no matter how reliable we may make our transmission, there is a considerable advantage both in reliability and in national safety in dispersing our generating stations fairly uniformly over the 132-kV network. There are advantages also in reduced transmission losses and easier regulation. This leads us to the alternative consideration of power stations suitable for inland sites, and this, in general, means the cooling-tower station. In such stations there is a loss of efficiency of the order of 5 or 6 per cent as compared with the more normal type.

I suggest that in favourable circumstances we may be able to compensate for the increased coal consumption associated with cooling-tower stations by locating generating stations on suitable coal-fields, thus reducing coal-transport charges. The proposal is, of course, not new, but I suggest that the establishment of the grid and the altered outlook in respect to the separation of generation and distribution centres to which I have already referred now leave the choice of site much freer, provided the water limitation can be put on one side.

There are many points to be considered in such a scheme, but I visualize the pure base load of the country being carried by a coastal fringe of large, completely reliable, primary power stations of the present type, employing still larger, cheaper, and more efficient generating units and supported by a series of much smaller secondary stations, say of the order of 60 000-kW installed capacity, located on selected coal-fields and normally operating on a 1- or 2-shift schedule. These last stations would be designed primarily for simplicity and low capital cost, rather than for ultimate reliability. They could be financed jointly by the supply authorities and the colliery owners, or by the supply authorities alone, with long-term agreements for low-grade coal delivered direct from colliery washing-plants into the power-station bunkers. Site works, coal storage, and spare plant, would be reduced to a minimum. In this manner both the capital and coal cost might be reduced in favourable examples to a degree sufficient for economic justification. Some natural water would, of course, be necessary for make up, and this might be supplemented by water pumped from the mines.

Such a scheme, if practicable, would have many advantages and is also a possible solution of the peak-load plant problem to which I refer later.

I must emphasize, however, the fact that the economic justification for such secondary stations as I suggest depends essentially on insistence on a rigid point of view in design. I have chosen the size of station, 60 000 kW, deliberately, as this represents what I call a typical grid unit and permits such a station to be treated as of no more importance than one of the generating sets in the prime base-load stations. This outlook permits the design of a station low in capital cost, by eliminating provision for extension, spare plant, large site works, and special arrangements to increase reliability. Given favourable circumstances, it is on capital savings of this type, and on savings in coal transport charges to offset loss of efficiency, that my proposal stands.

Another alternative would be to refit existing small stations with more efficient plant as supplementary stations on similar lines. Each case requires particular examination as it occurs, but such examples as I have seen indicate that whilst attractive examples will occur these will be much less frequent than might be anticipated.

Leaving this point, the most urgent requirement of the industry to-day is improvement in load factor generally, as here lies the chief key to cheaper electricity.

If I were asked what is the greatest unsolved problem in the industry to-day, I think I would say storage of electricity. In our industry, and in fact in most industries, load factor is a difficult problem. All public services, because they serve human beings whose requirements are inherently irregular, suffer from violent natural fluctuations in demand. This fluctuation is unlikely ever to be flattened out much at its source.

Interconnection in electric supply helps to a small degree by improving diversity of demand, but to achieve complete flattening in this manner we should have to envisage the interconnection, say, of England with Australasia, and this is not yet within the bounds of practical politics, although the interconnection of Scandinavia with Eastern Europe has already been suggested.

Again we can do things here and there to induce a special change in public habits, as the railway companies do by excursion fares and cheap night rates, but ultimately the only complete means of converting the fluctuating demand into a steady load is by the introduction of storage capacity, as in reservoirs in the gas and water undertakings or in warehouses for manufactured goods. In electricity we are able to do small things with water

heating and thermal-storage devices, but in the main no efficient storage means exists in this country.

On the generation side, off-peak steam storage and water storage have been applied. I myself feel that it is at least doubtful whether steam storage is really an economic proposition, although much is made of it in Germany. Off-peak water storage suffers gravely from large civil engineering costs, except in very favourable geographical conditions, and from the low efficiency of pumping and regenerating, and it has, therefore, a very restricted application. The droughts of the last few years have made me wonder whether some form of co-operation with the water-supply authorities might not occasionally make possible the combination of water reservoirs for emergency summer use with off-peak electric storage for winter use, in such manner as to reduce the civil engineering costs to both sides to practicable amounts.

The electric storage battery for main station purposes is, because of its cost, used little more than for control supply.

Failing storage, cheap peak-load stations are often proposed to reduce the capital cost of supplying the peaks in the load, although this is ideally a less satisfactory proposition than storage. The colliery-site station which I have already suggested is of this type, and water and Diesel-engine peak-load stations have been used. The only material example of the former in this country, and possibly the last with our meagre natural resources, is the Galloway water-power scheme described in our Chairman's Address 2 years ago.* The only other likely scheme of any magnitude at present in view is the well-known Severn scheme. This is again an example of a scheme which is impracticable without the conjunction of several diverse interests in the capital expenditure. It is shelved for the moment but is, I feel, far from dead.

Diesel-engine peak-load stations have been used to some extent in Germany. It may be possible to effect some saving in capital expenditure here, but it is difficult to get a true picture of costs, particularly maintenance costs, and the case is probably a border-line one. In particular I feel that most references to crude-oil engines nowadays take too little account of the uncertainty of cost of the crude oil, which is wholly of foreign origin, particularly if any serious extension of its use took place. A very small increase in present-day fuel-oil costs would eliminate the Diesel engine from consideration.

So much for the generation side of the problem. The consuming side, as I have already pointed out, can offer little but minor examples of heat storage, and our only real recourse, and an unsatisfactory one, is to multiple tariffs—the inconvenient excursion train of the supply industry.

The invention of a cheap and flexible means of electric power storage would alter the whole aspect of electric supply. Generation and distribution costs would be reduced considerably, voltage-regulation problems would be greatly eased, line duplication would frequently be unnecessary, reliability and safety would increase, preliminary economic development of isolated networks would become possible, and railway and other transport might be immeasurably cheapened.

The progress in electric tramways and railways during the period does not present quite so pleasing a picture as in other branches of the industry. The electric tram still remains the most economical and the most efficient method of handling bulk traffic in densely populated areas. Unfortunately, it suffers from the disability of confinement to a definite track, which causes it to impede the traffic flow, and as our cities and towns have proved quite incapable of meeting satisfactorily the conditions imposed by modern motor traffic the tramcar is accordingly being driven from the city streets. If we add the noise factor to this, I think we must reach the conclusion that in this country the electric tramway is dying. The trolley-bus is being substituted in many places, and this is sound economics, as it meets the problem whilst at the same time reducing the amount of capital jettisoned by the obsolescence of the tramway. At the same time it seems fairly clear that new urban developments are unlikely to employ trolley-buses although the trolley-bus is undoubtedly the most comfortable and efficient form of flexible city street transport available.

The examples of London and other cities abroad, although not by any means perfect, seem to point clearly to the conclusion that the best method of dealing with city or interurban traffic lies in the combination of a high-speed fixed system of transport, clear of the city streets and handling traffic in great bulk over major distances, and a separate and completely flexible street service linking up the short distances and dealing also with lightly loaded routes.

It is strange that others of our larger cities have not followed the example of London in this way by adding an underground service to their street services.

There is a growing strength of opinion that our arterial and interurban problems will never be solved adequately until entirely independent motor roads are constructed with separate up and down ways. The combination of these with light electric railways or trolley-buses for interurban traffic might do much to solve the general problem. I refer to this again later.

Whilst referring to road vehicles, I suggest quite seriously that too little attention is being paid in this country by the supply authorities to the electric battery vehicle. I am quite aware that small-scale experiments have been made from time to time, but I feel that we have been too easily discouraged, particularly as the electric battery has very much improved during the last few years and much steady progress is being made in the minor applications of the battery vehicle.

Several details have become more favourable. A 6-year guarantee is now possible with batteries, the art of light body design has increased greatly, roads have become smoother and flatter, and even the 30-mile limit may be a strongly favourable point, particularly if, as seems not unlikely, the bulk of the roads in the country become subject to the limit.

Almost despite the supply industry the use of battery vehicles for multiple-shop delivery work and for shuttle work is steadily increasing, and a number of municipalities and food distributors now possess considerable

* *Journal I.E.E.*, 1934, vol. 74, p. 58.

fleets of battery vehicles. It is noteworthy also that one London store has maintained a fleet of battery vehicles for over 20 years.

Abroad, however, much more has been done. In Germany, for example, the annual consumption of electric battery vehicles is already 120 million units, and in the Berlin Post Office division about 700 of the 1 100 motor vehicles are of the electric battery type. Very material advantages are claimed in total cost, life, safety, and speed, and they suggest from their experience that at least one-third and probably one-half of German commercial vehicles could with advantage be of the electric type.

That minor inroads into the transport industry have been possible almost without assistance from the supply industry as a whole, suggests strongly that the present case for the battery vehicle, at least for certain classes of work, is rather more than marginal, and that quite a little improvement in characteristics or, alternatively, quite a little improvement in facilities may turn the scale and produce an enormous extension in battery-vehicle application.

I feel strongly that the field is worthy of much more general exploration and encouragement than it gets, and that supply authorities and electrical manufacturers ought to accept as a natural development the use of battery vehicles for at least a part of their fleet.

The chief difficulty at present would appear to be the use of too small batteries, owing to their prime cost, and the ultimate aim would appear to be not the sale of batteries with vehicles but the hiring of charged batteries at garages in much the same way as petrol is now bought, which would result in vehicles extremely low in first cost, the use of batteries of ample size, and widespread facilities.

The Government and other bodies are spending much money on the development of processes for producing petrol from coal. I suggest quite seriously that they might turn their attention also to the battery vehicle, and that money spent on research and development offers for city use alone the probability of a quiet, fumeless, fireless, and safe means of transport, using home-produced fuel directly.

Passing to suburban railways, the advantages of the electric suburban railway were quite well established at the beginning of the period, and the underground Tube system as applied to London has shown itself particularly fitted to the problem of heavy city traffic. One feels that many of our larger cities would benefit by the application of this principle.

Main-line electrification has, strange to say, made no progress whatever in this country, with the solitary exception of the London–Brighton electrification, where, admittedly, the conditions cannot unreasonably be described as a combination of suburban and main line. The Weir Report has not been adopted. I feel personally that this Report was, if anything, a little conservative in its claims for electric main-line traction, and certainly if it were rewritten to-day, on the basis of the present low rates for money, it would present a much more favourable aspect. The real reason for the failure to adopt it lies, I think, in the necessity for very great capital expenditure at a time when the railway companies were really in serious financial straits.

I have no doubt whatever in my own mind that in a decade from now, for sociological reasons as well as technical, large sections of our main-line railways will have been electrified. It is a significant fact that in Germany and France together, where the conditions may be said to bear reasonable similarity to British conditions, there are already something like 2 500 route-miles of main-line electrification. In this matter of main-line electrification we are lagging behind the other principal countries of the world.

I suggest that, having regard to the present extensive road competition, a sound line of development for the railways would lie in the abandonment of a large proportion of the more lightly loaded branch lines and their conversion to well-illuminated motor roads carrying, in addition to general road traffic, a trolley-bus system as auxiliary to a simplified and electrified general railway system. Such a system would much facilitate rural electrification and would be worthy of the collaboration of the railways with the Ministry of Transport and the supply authorities on the basis of the railway providing the tracks, the Ministry the road work, and the supply authorities the lighting and general traction supply, the railways to retain priority bus-service rights.

The great advance in recent years of the mercury-arc rectifier has redirected attention to the possibilities of high-voltage direct-current transmission. I feel at the moment that the exponents of direct-current transmission tend to err on the side of overstatement. Quite apart from the many practical problems associated with the actual transmission, the great weakness in high-voltage direct-current work is the absence of means of voltage transformation. Much work is being done for this reason on re-conversion of direct current to alternating current and a measure of success has been achieved, and the development of really high-voltage rectifiers of the Marx type is very promising, but here, again, is a serious disability in the absence of means for the transmission of wattless or reactive kVA.

My immediate conclusion is that this matter can be left to take its normal course and that the problems will probably be solved in the next decade, but, even so, my present judgment is that direct-current transmission, when satisfactory, will only be used for the transmission of very large blocks of power over long distances and will not have a general application in this country.

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By H. MANLEY ROBERTS, Member.

"THE GRID AND THE INDUSTRIAL LOAD"

(*Address delivered at* CARDIFF, 14*th October*, 1935.)

May I begin by expressing my deep appreciation of the honour you have conferred upon me by electing me Chairman of this Centre. I am, I believe, the first colliery engineer to be elected to such a position.

I propose to put before you my views as to the relationship between the colliery electrical engineer and the Central Electricity Board.

First of all I should like to remind you of the many phases of electrical work for which a colliery electrical engineer is responsible. He has to be a combustion engineer, generating-station engineer, and transmission and distribution engineer, and has to be able to apply himself to the use of electricity so generated and distributed. In this connection he has to be conversant with pumping, ventilating, and winding plant, and in some cases a rolling-mill plant as well. I mention these points to show that on the whole he is a person capable of taking a wide view of industrial matters.

Turning to the grid, it becomes interesting to see in what way it has helped industrialism. In the case of the "South-West England and South Wales Electricity Scheme 1929," the Central Electricity Board state that the larger part of the area has been without a supply of electricity. This is probably true when viewed from the angle of domestic load, but it cannot be substantiated when viewed from the industrial standpoint. For example, most colliery and steelwork undertakings worthy of the name had their own generating plants and high-voltage transmission systems in full operation long before 1929, and yet in reviewing the matter of the possible growth in demand the Central Electricity Board practically ignored the existing industrial load and considered that they would reach very high figures from domestic loads, i.e. flat-irons, cookers, neon signs, etc., plus the little ray of hope in the shape of railway electrification, which up to the present time does not appear to be forthcoming. It is difficult to imagine that the railways in South Wales will be electrified in the immediate future. A point of interest here is the quite recent development in regeneration. The mercury-arc rectifier is now applicable to regenerative conditions, and it occurs to me that the "pit to port" traffic will, if developed on these lines, have a considerable bearing on the total railway load to be imposed upon the grid in this area, because the units per train-mile will be considerably reduced if the bulk of the load is to be run on the brake.

Has the estimated maximum-demand figure of approximately 500 000 kW been reached? I venture to say that it has not, and he would be a bold prophet indeed who would predict when the present industrial slump will lift to such an extent as to put the estimate made in 1929 within the realms of possibility. It is obvious, therefore, that the figures of the Commissioners will not be achieved by domestic loads only, but that they will have to tackle in a very determined manner the tapping of existing industrial loads.

I think the Central Electricity Board recognized that the South-Western Area was likely to be one offering difficulties for development, and yet the disregard of the magnitude of the existing industrial load is surprising. In giving a list of stations from which it would be possible to obtain electrical energy it is said that the scheme has not made provision for the utilization of electrical energy from any privately-owned generating plants in the colliery districts of South Wales, and that when the transmission system is constructed the Central Electricity Board may be able to effect suitable arrangements for the use of any surplus energy which may be available from such sources—a definite indication that loads existing at such sources have been disregarded.

For instance, my own company—whose main job is to produce coal—as a side line generates nearly as much electrical energy as Cardiff and Newport put together, and again, as a further indication of the amazing loads available, I have in mind four colliery companies in South Wales alone whose total load exceeds 80 000 kW. Further, it is estimated that 96·3 per cent of the output of coal in Great Britain was produced by colliery companies using electricity for the whole or part of their power requirements. Of the total output 60·6 per cent was obtained by colliery companies who owned and worked their own power plants; 18·8 per cent by colliery companies partly dependent on bulk supply; and only 16·9 per cent wholly by bulk supply.

It can also be accepted that colliery electrification is by no means complete, and here alone in the coal-mining industry is a very substantial industrial load yet to be taken over by the Central Electricity Board.

So far I have only referred to colliery industrial load. There yet remain for consideration heavy rolling-mills, and tinplate and sheet mills, and I know of many such plants, representing thousands of kilowatts, operating from their own power plants, who hardly ever dream of bulk supply as an alternative source of power.

Apart from the proposed G.K.B. load at Cardiff and the Whitehead undertaking at Newport, how many heavy steel and iron plants of any size have the Central Electricity Board dealt with in any way in the South-West England and South Wales Electricity Scheme? What is holding back these users of electricity from obtaining supplies in bulk? There must be definite

Typical Cost Sheet of Industrial Company

Cost of Electricity Generated.

	This Month	Last Month
B.O.T. units generated		
B.O.T. units generated (average per week)		
Coal used, and price per ton		
Breeze used, and price per ton		
Coal and breeze used, lb. per unit		
Gas to boilers (coke ovens), cub. feet		
Gas to boilers (blast furnace), coal equivalents		
Load factor		

	£	s.	d.	Cost per Unit: This Month	Cost per Unit: Last Month
Foremen					
Stokers					
Ashmen					
Labourers					
Boiler scalers					
Switchboard attendants					
Driving pumps, d.c.					
Driving generator (new), a.c.					
Cleaners					
Storekeeper					
Masons					
Carpenters					
Painters					
Smiths and fitters					
Sundry other labour					
Clerks and draughtsmen					
Metal burner					
Engineering Dept.—Electricians					
Smiths and fitters					
Charges on ditto					
TOTAL LABOUR					
Coal					
Breeze					
Gas to boilers (coke ovens)					
Gas to boilers (blast furnaces)					
Engineering charges					
Stores—Invoices					
Stores—Sundries					
Ironwork					
New castings					
Bricks					
Mortar					
Traffic					
Wagons					
Workmen's compensation					
National Health Insurance					
National Unemployment Insurance					
Incidentals					
Rates					
Crusher ballast					
Pumping cost proportion					
Depreciation					
Condenser pump					
Ganisters					
Electricity to generating station					
Electricity to boilers					
Electricity to turbo-generator pumps					
TOTAL					
Wages above standard					

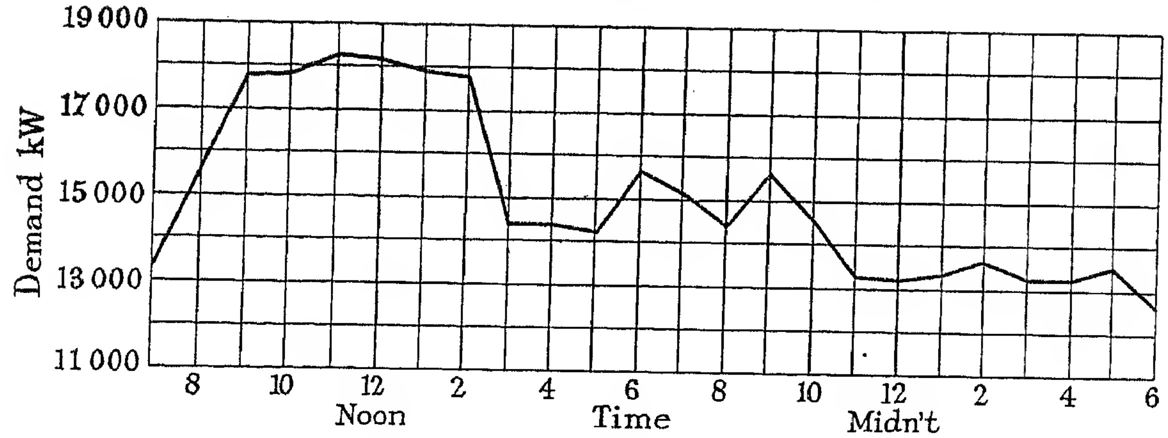

Fig. 1.—Industrial load chart.

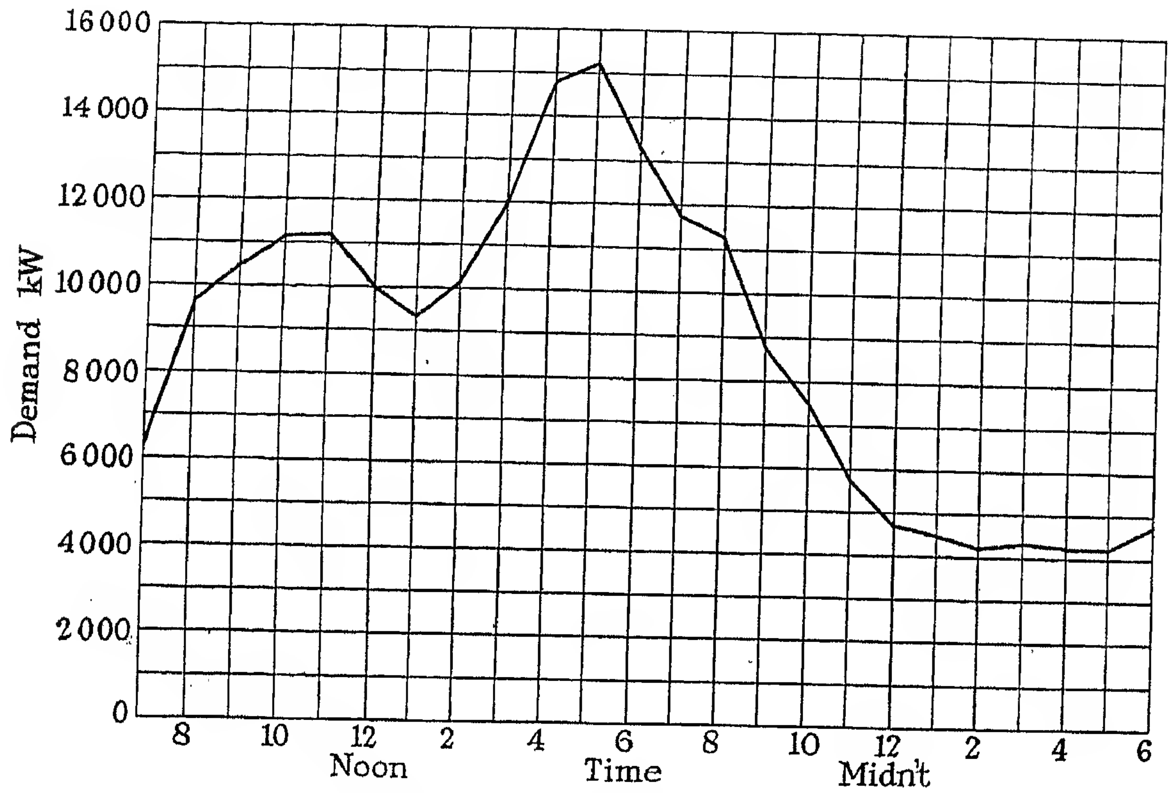

Fig. 2.—Non-industrial load chart.

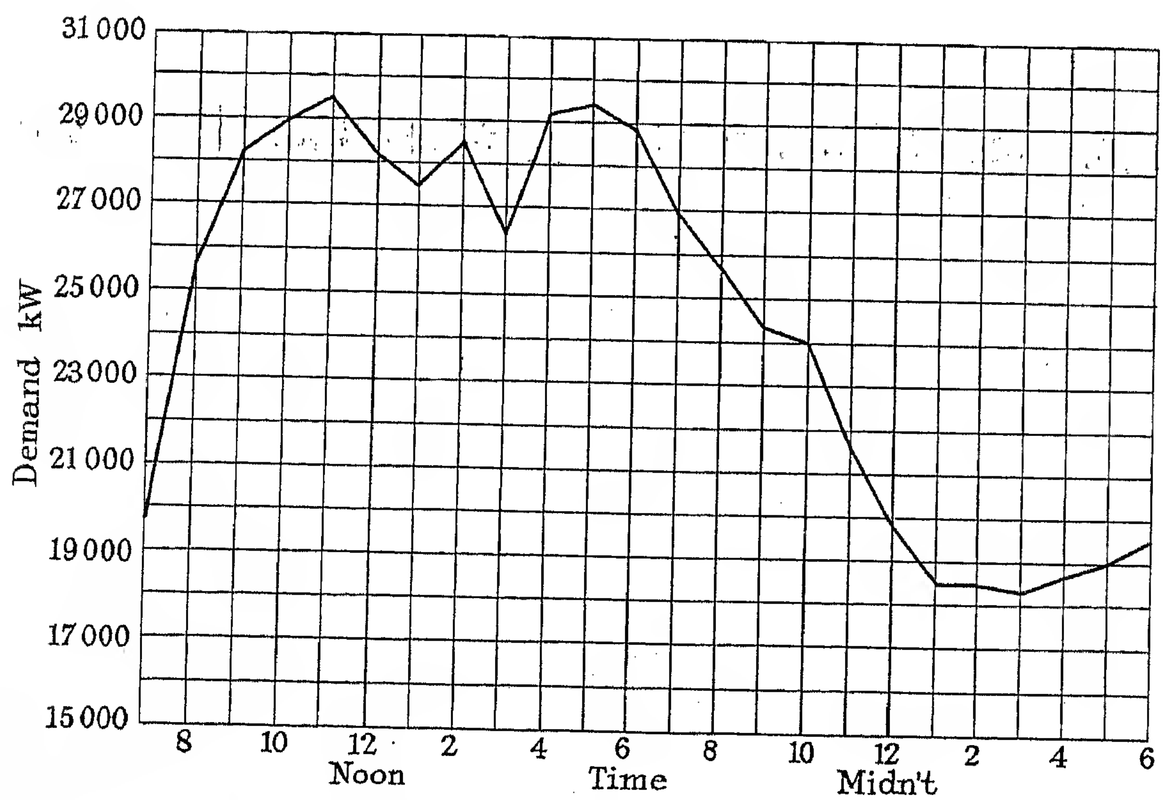

Fig. 3.—Combined load chart.

reasons. Is it price or the (as yet) non-existence of the necessary transmission lines, or both?

Let us examine the price first of all. It would be difficult to imagine an industrial board who would not be only too glad to shut down a generating station with its attendant staff, maintenance, difficulties of operation, etc., and obtain an adequate and reliable bulk supply at the same cost per unit, or, better still, at the lower figure they were led to expect when the grid was an accomplished fact. That the price per unit for supply in bulk is higher than the cost at which most industrial companies are able to generate cannot be disputed. I know that when my company supply an authorized undertaking with electricity in bulk the value of the unit is very low, but when I approach an authority and attempt to obtain a supply in bulk then the value of that unit mysteriously jumps to a figure that makes it impossible for further consideration. It has been suggested, for example, that the grid could make use of current in blocks of 10 000 kW at a price not exceeding 0·15d. per unit, and I know of contracts existing at 0·25d. per unit.

On the other side of the picture, when one tries to purchase in bulk from an authorized undertaking the quotation is £5 15s. per kVA per annum of maximum demand, plus ½d. per unit for a term of not less than 10 years. The consumer is also expected to bear the cost of the construction of the high-tension line to his substation and the necessary apparatus contained therein.

Now there is nothing mysterious in the way the industrial companies generate electricity or prepare their cost sheets. I am aware of the criticism levelled at colliery companies—that their cost is not strictly comparable and that they leave out such items as depreciation, rates, etc., and put in coal at a favoured rate—but I can assure you that such is not the case and it is really time that this ostrich-like attitude was set aside and the figures closely examined. It must also be kept in mind that a percentage of coal raised is not saleable—but not necessarily unusable. Washery slurry is an instance; this slurry is of such low calorific value that it is not economic to pay carriage on it and use it elsewhere. If, however, the colliery company did not use it they would be faced with further expense for moving it and dumping it. This also applies to coke breeze. It must be realized, therefore, in this particular instance, that a colliery company would be justified in taking credit for it into their costs. In the following costs, however, this has not been done. It is not a question of charging it at a favoured price, because it is there for anyone to have at the same figure, and it is simply to find a commercial use for it that the colliery companies have used and will continue to use it themselves.

An example of an industrial company's cost sheet is shown on page 41. I think you will agree that nothing has been left out. It must also be understood that large groups of collieries are able to achieve a load factor on their power stations by arranging pumping loads, etc., on the "off-coal-getting" shifts, and many other such ruses, all tending to produce a load curve such as is shown in Fig. 1. Compare this with Fig. 2, which is a non-industrial load curve. It is safe to say that cheap production in the first case is easier than in the second, and here probably is the chief reason for the difference in cost. If we impose one curve on the other we get Fig. 3. Now, I should be delighted to have such a load curve to work to, and I feel sure my costs would be below any of the following figures, which represent actual costs when catering for the load curve shown in Fig. 1.

1934		1935	
August	0·221d.	January	0·180d.
September	0·224d.	February	0·222d.
October	0·210d.	March	0·222d.
November	0·198d.	April	0·216d.
December	0·179d.	May	0·218d.
		June	0·219d.
		July	0·222d.

It does not require much imagination to visualize how these costs would be further reduced if the load curve were as shown in Fig. 3. There would be a further reduction if modern generating plant operating on large loads were used instead of probably somewhat old and antiquated plant operating on comparatively small loads.

If we take the average of the costs already given we get 0·211d. per unit. This can be compared with the average price per unit which the 16·9 per cent of the colliery companies who obtain their supply in bulk have to pay, namely 0·518d. These, then, are representative figures to which the Central Electricity Board have to get down.

How this state of affairs is to be brought about is the burning question. I should have thought that it would have been better if the Central Electricity Board in the past had made full use of any industrial stations by linking them up with a high-tension network and utilizing all surplus plant—waste heat in the form of exhaust steam, coke-oven and blast-furnace gas, etc.—instead of their policy of providing a super-abundance of new capital stations.

Had they taken a closer view of the geographically correct positions of their overhead lines in relation to existing industrial load, then matters to-day might have proceeded a little farther towards that Utopian state of affairs—an abundant and cheap supply of electricity.

Visualize, for instance, the position of the grid transmission lines in South Wales between Gloucester and Swansea. I venture to suggest that had they been 20 miles to the north they would have been in a more favourable position, for it is 20 miles north of the sea line that the majority of the load in South Wales and Monmouthshire lies, except, as I have mentioned before, the two outstanding examples of industrial load at Newport and Cardiff. I venture to say that the enormous expenditure of capital would not have been necessary had this policy been pursued, and that capital stations of any considerable magnitude would only have been necessary when industrial generating stations became overloaded. This would have been the time to erect super-stations on the coast.

I wish to conclude by saying that these are my views only, and I am fully aware that they will not meet with general approval. Be that as it may, if I have excited the interest of those of you whose actual business this is, I feel I shall have achieved an end.

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By Colonel H. CECIL FRASER, D.S.O., O.B.E., T.D., Member.

"THE DEVELOPMENT OF OFF-PEAK LOAD"

(*Address delivered at* LEEDS, *15th October*, 1935.)

The development of electrical load is a subject of intimate concern not only to the supply engineer but to the electrical industry as a whole, since any increase in output of supply undertakings will necessarily react to the betterment of ancillary electrical industries.

I have therefore thought fit to survey the problem of load-building in the light of recent developments, with special reference to so-called "off peak" supply which, it is felt, is the most promising field for disposal of electrical energy coincident with the complete utilization of the invested capital in plant and mains.

Diverse Loading of Supply Systems

In the past, innumerable attempts have been made to devise efficient physical or chemical means for the storage of electrical energy, but up to the present time little commercial success has been achieved. Consequently, electricity continues to be supplied on systems which make no provision for its storage and, therefore, the maximum demand made by each user and the time of its occurrence have an important relation to the cost of supply. The incidence of the consumer's maximum demand is modified according to the extent and diversity of loading of a system as a whole; the size of each distribution main is determined by the simultaneous demands of the group of consumers on that main; the size of each substation depends on the simultaneous demands on the various parts of the distribution network; and the demands on the transmission mains and on the generating station depend on the simultaneous demands at the substations.

There is usually a time diversity between the demands of consumers on the same main, between those of the mains supplied from the same substation, between substations, and between transmission mains. To take a typical case where the annual load factor of the generating plant is 33 per cent, that of the individual transmission mains and substations is 22 per cent, and of the individual distribution networks only 15 per cent, whilst the average of the consumers' load factors may be as low as 12 per cent.

Moreover, as the total of the economies which result from the improvement of load factor of any part of a supply undertaking depends on the capital expenditure concerned, it is important to note that the proportion in most undertakings is of the order of 35 per cent on the generating stations, 25 per cent on the transmission mains and substations, 30 per cent on distribution mains and services, and some 10 per cent on other works, and that the expenditure on transmission and distribution works continues to show an upward tendency.

The improvement in load factor coincident with the increase of load in the past has fostered the belief that time will provide a solution of the load-factor problem, but to-day, with the growth of domestic load, this view is being abandoned.

In the past, lighting demands have determined the time of peak load, but to-day not only has the incidence of the domestic load greatly reduced the importance of the lighting peak but progressive undertakings are now experiencing morning peak-loads during critical winter months. This fact is of great economic importance to the development of the electric supply industry in that when morning peak-loads arise from domestic demands the overhead charges for peak demands must be transferred from lighting to domestic load, with a consequent increase in the cost of supplying the latter. Moreover, the effective diversity factor of domestic apparatus is greatly reduced when a morning peak-load occurs, and with the continued growth of this class of load the position will become increasingly more difficult from the undertakers' standpoint in so far as load factor and demand charges are concerned.

An analysis of a characteristic load curve obtained during the most critical period in the month of December shows that whereas the afternoon peak varies considerably from day to day in both extent and time of occurrence, the morning peak is almost stationary between 7.30 and 8.30 o'clock and this is undoubtedly largely due to breakfast-time domestic load. Generally speaking, it may be said that little variation exists in the breakfast-time period in this country, particularly in urban areas, and it follows that domestic heating and cooking load, during the winter months, may substantially increase the maximum demand of a supply undertaking, and will become more and more important. In this connection the Monday morning peak is of particular interest since the maximum power and heating loads usually synchronize during this period. In the case of power load in industrial areas the individual loading of factory installations is often 20 per cent above normal after a cold week-end, due mainly to increase in oil viscosity when machinery is idle, and actual observations indicate that, on the average, this adverse effect does not subside until 10 a.m. In addition, Monday is the traditional wash-day in most parts of the country, and wash-boilers and immersion heaters add their quota to the usual heavy demand created by fires, water-heating, cookers, and lighting, during the breakfast-time period.

Off-Peak Load

The gradual improvement in thermal efficiency of selected stations is increasingly making possible the

disposal of energy on remunerative terms in competition with other sources of heat or power when such supplies can be given on an off-peak basis so as to secure the fuller employment of the capital invested in plant and mains. The potential field of application is immense and, subject to the introduction of an efficient control system, should, in addition to increasing power load, tend to make electricity the universal agent for heating purposes.

In framing tariffs for off-peak supplies it will be remembered that the extra cost of energy at the consumer's terminals is principally the cost of coal per unit, since nearly all other costs are governed by the demand made at the time of the peak load. In the case of large base-load stations the actual coal cost will amount to less than 0·09d. per kWh, and after making due allowance for transmission losses an all-in cost of 0·1d. per kWh will form a reasonable cost basis for off-peak loads, when little capital expenditure is incurred in giving a supply.

Table 1 will give some indication of the potential field for development, but no doubt many other applications will materialize when off-peak facilities become generally available to the public; in fact, the greatest difficulty will be met, not in finding consumers but in deciding to whom the facilities are to be offered. It is apparent that many existing power consumers would willingly accept the inconvenience of restricted supply for a few hours a day in the winter months for the privilege of purchasing energy at a greatly reduced cost, and as the available off-peak energy is a limited quantity it will be in the best interests of the undertaker to confine off-peak facilities to profitable spheres of application which cannot be served in the ordinary way owing to severe competition from other sources of heat and power.

Table 1

Group "A" Heating loads with thermal storage	Group "B" Power loads with stored medium	Group "C" General
Domestic water-heating Domestic cooking Space heating Process heat for hotels, factories, etc. Air conditioning Hothouse heating Soil heating	Water pumping Sewage pumping Hydraulic pumping Liquor pumping Refrigeration Electrolytic processes Electrothermal processes Electrochemical processes	Industrial loads where power costs represent a large proportion of the cost of the manufactured product Industrial loads utilizing process steam and having stand-by plant (interchange of supply)

Controlled Domestic Supplies

Competitive interests are fully alive to the potentialities of domestic load and, as a result of intensive publicity campaigns, have secured a strong position in the cooking field and have now turned their attention to water-heating.

From the supply undertaker's standpoint there is no doubt that domestic water-heating is one of the most promising fields for off-peak supply and, on a conservative basis of 2 units per person per day, will go a long way towards absorbing all available off-peak energy. Electricity possesses many inherent advantages for domestic duties since it creates no products of combustion and no special flues are required; moreover, electrical heating equipment can be readily adapted to existing domestic water cylinders so as to operate in parallel with fire-back boilers, which arrangement, on the score of low capital outlay, economy of operation, and conservation of space, often presents advantages as compared with the installation of independent water-heating apparatus, provided always that thermostatic control and efficient lagging is fitted.

By far the greater proportion of existing electric water-heating is performed by means of immersion heaters or circulators attached to unlagged cylinders and controlled by 3-heat switches, making it necessary for the consumer to anticipate demands for hot water by switching at the appropriate time: in practice this inefficient arrangement severely limits the utility of the apparatus. When a thermostatically controlled and lagged cylinder is fitted the use of electricity is encouraged, as hot water is always available; moreover, the electrical rating of heaters may be considerably reduced, with a corresponding reduction in initial cost of heaters, switchgear, and wiring, to offset the additional cost of thermostatic control and lagging material.

Another interesting field of application is that of domestic cooking, and in my opinion an efficient off-peak control system will make possible the production of an effective thermal-storage cooker, which will not only eliminate demand charges but will go a long way towards removing the inherent defects of modern cookers such as excessive heat inertia and cooling-off losses. As regards thermal storage, it will usually be only necessary to provide sufficient heat for breakfast-time use on the assumption that the system peak occurs during this period, and consequently the continuous heat-dissipation losses will be small.

Recent extensive interruptions of supply have had serious repercussions in destroying public confidence in electric supply, and in this respect the thermal-storage principle will be of great value in providing a reserve of heat to carry over a period of interruption, and will also facilitate the work of the supply engineer in permitting, without serious consequences, a reduction in load in the event of a partial shut-down.

Controlled Space-Heating Supplies

The heating of buildings of every description offers an almost unlimited field for disposal of off-peak energy,

but it is in this field that the most serious competition is met from other sources of heat. Difficulty may arise in justifying the adoption of electric heating on a purely thermal comparison with coke- or oil-fired boilers, but, on the other hand, saving in labour costs and improved service will often justify a remunerative charge for energy.

In this connection I favour the adoption of electrode or resistance boilers to replace existing coke- and oil-fired boilers, as such equipment is comparatively inexpensive and readily adapted to existing installations. Where separate room temperature control is necessary, thermostatic hot-water valves can be utilized, and this effects economies comparable with thermostatically controlled electric heating.

It has been claimed with some justification that the danger of fire is ever present with electric heaters of the tubular or panel type, owing to the possibility of a serious rise in temperature when the surface of the heater is accidentally covered with clothing or any material which has a lagging effect. When water is used as the heating medium this danger does not arise, since under no conditions can the surface temperature rise above boiling point.

Controlled Horticultural Supplies

The present national economic policy has given a great impetus to the home production of fruit and vegetables which have hitherto been imported into this country, and electricity should play a great part in future development in this connection.

The recent work of the German scientists on the propagation and acceleration of plant growth by the application of liquid synthetic earth under artificial conditions enables one to visualize future conditions when special crops will be produced in buildings employing artificial heating and lighting. An intermediate stage of development has already come into prominence in the application of soil heating, and electricity is the only efficient medium for this purpose.

The application of off-peak control is essential for the successful exploitation of this field of development, and the thermal storage available in the soil and other mediums will make possible long off-peak periods without detriment to satisfactory operation; in fact such conditions will tend to imitate natural conditions of plant life. It is known that light is essential for the ripening of fruit crops and also that high-frequency discharges are beneficial, and here again off-peak energy may be utilized in the future.

Controlled Power Supplies

The Central Electricity Board's policy of closing down small obsolescent central stations has had the effect of flooding the market with turbo-alternators, boiler plant, and equipment at knock-down prices. This plant is being absorbed by industrial users to the detriment of public supply, since the almost complete elimination of capital charges places the user in a strong position in so far as the cost of generation is concerned; also, the position is aggravated by the increasing utilization of exhaust steam for process work, and the trend of events in the United States of America gives some indication of future developments in this country. Another factor which militates against the adoption of electric supply is the reluctance of industry to dispose of existing moderately efficient plant at scrap value; such plant may stand at a high book value and this has to be contended with in changing over to electric supply.

It is apparent, therefore, that load of this nature can be dealt with most advantageously on an off-peak basis by arranging for an interchange of supplies during critical winter months, and the additional security of supply provided by such a working arrangement will often make a strong appeal to the user. In many instances the user possesses a margin of plant capacity over and above normal requirements, and this can be utilized to feed back into the supply system during critical peak-load periods, to the mutual benefit of supplier and user.

In the case of factories utilizing process steam or collieries' exhaust steam, an interchange of supplies can be arranged throughout the year and economies effected by discontinuing the use of live steam. It is well known that pass-out turbo sets are often inefficient owing to diversity in demands for heat and power; i.e. steam is often required when the demand for power is low, and, inversely, little steam is available when demand for power is high. Where reciprocal supplies are arranged this difficulty is overcome, since the user is in a position to feed back into the supply system any available surplus power.

In the past, difficulty has been encountered in effecting parallel operation, but this has usually been confined to instances when the supplier has attempted to give a supply which has represented only a small proportion of the user's total requirements. There appears to be no reason why parallel operation should be limited to large users having turbo plant, and the load factor of an undertaking can be improved, with a corresponding reduction in demand charges, by utilizing all available industrial plant. The difficulties associated with the cyclic speed variation of reciprocating engines can be overcome by utilizing induction or synchronous induction generators. That is to say, a motor is used to drive the user's works during off-peak periods, but during critical peak-load periods the user's engine is brought into operation to carry the works load, and all surplus power is fed back into the supply system via the motor, which then functions as a generator. Such an arrangement is simple in operation, as no synchronizing equipment is necessary.

An important field for development of off-peak power load is that of pumping and kindred duties provided with stored medium as itemized in Table 1.

It is interesting to note that the dearth of accessible water catchments, together with the high capital charges incurred in constructing reservoirs and pipelines, favours the increasing utilization by water-supply authorities and industrial users of artesian wells and other available sources of water supply requiring pumping plant. It is a regrettable fact that in the case of some large installations of this kind recently put into service, steam power has been adopted, and in order to compete successfully it is advisable that electric supplies for this duty should be on an off-peak basis.

The control of load of this nature differs from that of

thermal-storage apparatus, in that it is necessary for the supply authority to accept liability for providing energy under exceptional emergency conditions, irrespective of the effect on system maximum demands; for example, in the case of a water pump discharging into a reservoir it is usually vital that the pump should operate in the event of the water falling below a predetermined low water-level, and under such conditions suitable means must be provided to render the control system ineffective. In practical operation, particularly with automatically controlled plant, the risk from the undertaker's point of view can be almost completely eliminated by having a small margin between the normal high and low water operating levels, so as to utilize almost the whole of the available storage for "off peak" periods. Under such conditions, system demand is only effected in the unlikely event of a serious plant breakdown on the critical day of maximum demand, and having regard to the fact that pumping plant of this kind is usually duplicated, the liability is negligible.

Control System

In some instances an improvement in load factor has been achieved by giving limited time supplies restricted at anticipated times of peak load by time-switch control, but with the growth of such supplies it is obvious that time-switch control will become impracticable since peak loads will occur more frequently than at present and at times which cannot be predicted with certainty.

In other instances attempts have been made to improve load factor by the installation of load-levelling apparatus on consumers' premises; for example, a load-levelling switch may be arranged to switch off a water heater when a consumer's total load exceeds a predetermined value. Whilst the installation of such apparatus may be beneficial in reducing the maximum loading of services or small distributors, it can have little effect on substation or system maximum demands, since the improvement in consumers' load factor is accompanied by a corresponding reduction in diversity factor. In other words the principle of load-levelling is based on the false assumption that the consumers' maximum demand coincides with that of a supply system as a whole, and a knowledge of diversity effects makes it apparent that the net result of load-levelling in connection with a system having a great diversity of loading may be infinitely small.

The desiderata of an ideal "off peak" control system to cope with future developments in the electric supply industry may be summarized as follows:—

(1) In order to secure the full employment of the plant and transmission mains of a supply undertaking, the users' restricted load must be controlled from the main control centre according to the actual load at the time.

(2) In order to secure the full employment of substation equipment and distribution mains, subsidiary control of users' restricted load must be effected according to the actual load on the substation supplying such load.

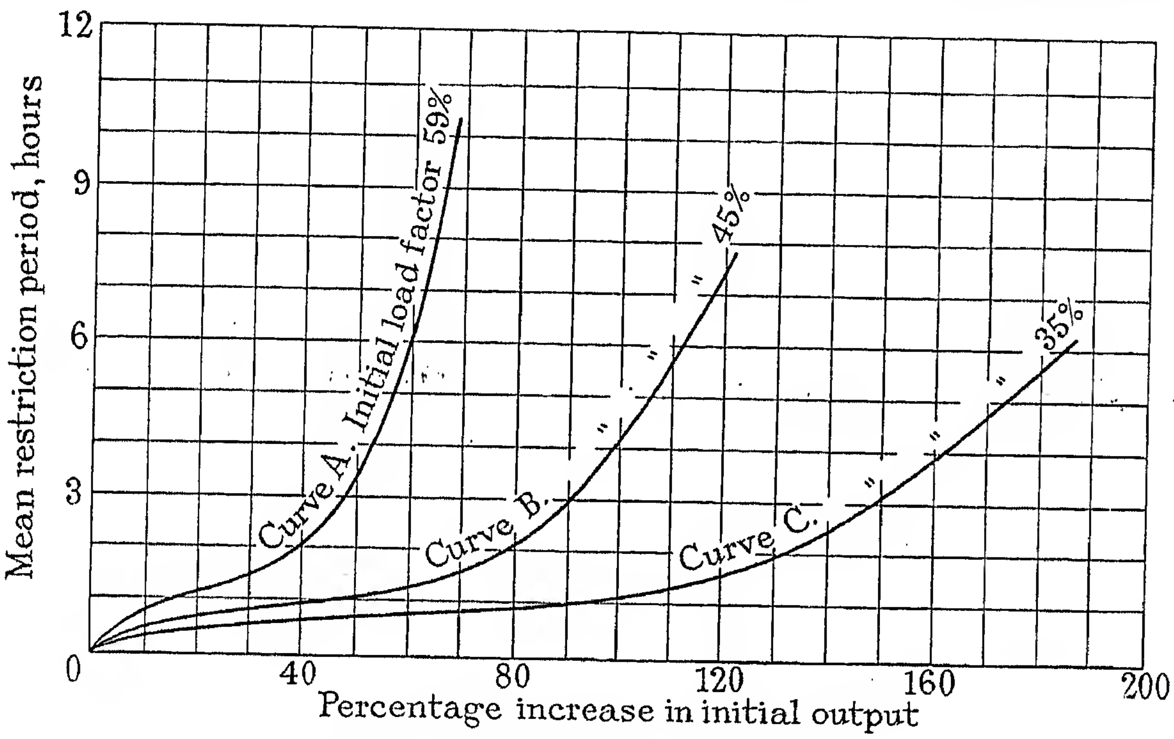

Fig. 1.—Addition of controlled load.

(3) In a supply system having a large number of restricted consumers the controlled load must be disconnected and reconnected progressively in units to coincide with variations of system load so as to maintain a constant load on the system.

(4) In order to permit the connection of a large proportion of restricted load to a supply system without inconvenience to consumers and with a minimum of thermal storage, the load must be controlled selectively; that is to say, the consumer most urgently needing the supply must take precedence.

(5) When a supply system has a large proportion of controlled load, manual control from control centres is impracticable and automatic control must be provided.

(6) The control system must be capable of being readily adapted to existing supply systems without the need for special control conductors.

(7) The users' control switch must be simple and inexpensive in construction since it will be required for a large number of small pieces of apparatus such as domestic water-heaters.

It is apparent that the above-mentioned requirements

can only be satisfied by some form of superposed high-frequency control, and having regard to recent developments in this connection I am confident that a control system of this kind is practicable and will, when available, form a sound basis for future development of off-peak load.

The progressive control action referred to in (3) is essential to provide a gradual transition from one state of load to another so as to follow the contour of a system load curve, and without this feature little improvement in load factor can be achieved. In addition, the selective action referred to in (4) will, by taking advantage of diversity in demands for heat or other stored medium, permit the connection of a large proportion of off-peak load without inconvenience to consumers and with a minimum of thermal storage. This feature would be of particular value in making possible the design of an effective thermal-storage cooker.

The operation of such a control system will be approximately as follows. Control of off-peak load will commence on the non-diminishing maximum demand being exceeded either at the central station or substation, and thereafter during a period of increasing load individual consumers will be isolated in turn until the maximum demand of unrestricted load is reached, when the whole of the off-peak load will be disconnected. During a period of diminishing load, reconnection will take place in a similar manner, until, when the total load falls below the maximum demand of unrestricted load, the whole of the off-peak load will be reconnected. The order in which the individual loads are disconnected and reconnected in turn will be determined by the consumer's resources at the time. For example, in the case of thermal-storage load the order will be: during a period of increasing load the hottest first and the coldest last, and during a period of diminishing load the coldest first and the hottest last.

Fig. 1 has been prepared in order to indicate the great scope for disposal of off-peak load and to facilitate the calculation of necessary thermal storage under known conditions of initial and ultimate load factor.

The three curves, A, B, and C, refer to undertakings having initial load factors of 59, 45, and 35 per cent, respectively, increase in output being shown as abscissæ and mean restriction period as ordinates. The curves are based on conditions existing on the day of annual maximum demand when morning and afternoon peaks occur, but it will be understood that the average restriction period over the months of November, December, January, and February, will be appreciably less than the figures shown, and, generally speaking, no restriction will be necessary during the remainder of the year.

With a selective control system the mean restriction period, which decides the necessary thermal storage, need not apply to each installation and refers only to the average value for the whole undertaking; thus where large storage facilities are available they may be employed to help other installations where bulky thermal-storage apparatus is objectionable, and in view of diversity in demands for heat no provision need be made for the abnormal requirements of each installation.

In applying the curves it will be remembered that initial load factor refers to normal unrestricted load, and, having regard to the fact that undertakings usually have a proportion of load to which control may be adapted, the initial load factor will be less than the recorded load factor under existing conditions.

Conclusion

I have found difficulty in dealing adequately with this important subject within the scope of this address, but I hope that my remarks will tend to encourage a long view of supply problems and perhaps create interest in an important aspect of load building.

SOUTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By F. H. CLOUGH, C.B.E., Member.

(*Address delivered at* BIRMINGHAM, *16th October*, 1935.)

In electricity we have a form of energy which can readily be produced from mechanical energy with an efficiency closely approaching unity. It can be converted from one voltage to another, transmitted over long distances, and finally reconverted to mechanical energy with similar small losses. Electrical energy can also be converted into heat energy with approximately 100 per cent efficiency but, unfortunately, the efficiency of the reverse process is still very low. The amount of light that can be produced from a given quantity of electrical energy is also low, but the process is so simple and convenient that most artificial light is now produced electrically. It is not surprising that there is a large and increasing demand for this convenient form of energy, and that a large proportion of the engineering activities of this country are devoted to the electrical industry in its various branches.

In our Institution we meet to exchange views and experiences with one another in order to advance the technical knowledge on which this great industry is based. As my own experience has been gathered almost wholly from the manufacturing branch of the industry, I propose first of all to talk a little about the activities of manufaeturing concerns in a general way. In the later part of this address I intend to discuss two important problems of current interest, namely "Circuit Interruption" and "Voltage Impulses."

STANDARDIZATION

Modern manufacturing methods tend to become highly specialized and for that reason are at their best where large quantities of exactly similar articles are made. When such conditions exist it is usually found that the methods employed by electrical manufacturers are of the best and most modern type, probably for the reason that the industry is young and not hampered by traditions and methods based on long usage that cannot be readily changed. Unfortunately, on the other hand, owing to the electrical industry's comparative youth, its products are continually changing, and mass-production methods of manufacture cannot be used to any great extent. The diversity of electrical products is very great—a motor suitable for driving a paper-making machine is unsuitable for a cement mill, and one for a mining hoist cannot be used for a locomotive. Making apparatus suitable for all types of industry calls for a large engineering effort as well as versatility in the factory. The consulting engineer and the engineer connected with the particular industry concerned play important and useful parts in the application of electricity, but both of these engineers may be handicapped through not knowing details of the manufacturer's facilities. It is necessary for the electrical manufacturer, therefore, to employ engineers to design the actual electrical apparatus required, and others, who are familiar with each particular industry, to study the best means of applying electricity to it. In many cases standard motors and other apparatus can be used—perhaps not for the main drives but for all sorts of auxiliary purposes. The recent standardization of type of supply, frequency, and voltage, has done much to enable manufacturers to concentrate on standard types of apparatus, with great benefit to industry in general in giving lower prices and better deliveries. Standardization properly applied has, and will continue to have, an important influence on our industry, but it must be done with discretion. On the one hand it may be too early to standardize some articles or ways of doing things because experience has not yet proved which are best articles or methods; on the other hand, several alternative methods may have become usual, all of which are good; and although it would be highly desirable to have one only, vested interests in the others, and the cost of changing, may be too great. The creation of the Central Electricity Board, backed by an Act of Parliament, was necessary before frequency could be standardized in this country.

Undoubtedly the people best qualified to decide what degree of standardization is desirable in the electrical industry are the engineers engaged with that industry; in other words, ourselves. Those of us associated with manufacture are best able to appreciate the effect of standardization on the cost of our products, whereas those associated with the use and operation of the various classes of electrical equipment can give valuable advice on the operating characteristics of apparatus to be standardized. In the British Standards Institution we have a typical British institution, supported largely by our own industry. Under the guidance of its permanent officials most of the work is done by our own engineers; and in the form of a welcome financial grant the Government give it just the right amount of official status.

Outside the activities of the British Standards Institution we eould, I think, standardize our practice more than we do. The wide diversity of apparatus installed for achieving almost identical results, although it may lead to progress in many cases, more often only means greater expense for both manufacturer and user.

TRAINING OF ELECTRICAL ENGINEERS

Experience gained by working for a few years in a large manufacturing organization forms an essential part of the training for a young engineer after he finishes his school or college education. He has the opportunity to attain manual skill in the use of tools; he can see organized methods of making small parts on the one hand, and the building of large maehines on the other. Later on he will have the opportunity of spending time in the drawing office, the testing department, on outside con-

struction, and probably also in the designing, management, and commercial offices. Most large companies realize the importance of this training, both to the young engineer and to themselves, and have an extensive organization for supervising the young engineers and arranging for them to get the best experience. This organization keeps in touch with the universities and technical colleges and finally finds positions for the young men either in one of the company's own departments or in some position outside its own activities where his education and experience can be best utilized.

RESEARCH

In talking of the technical activities of a manufacturing company, reference must be made to the large amount of physical, chemical, mathematical, and technical research and experimental work, that is carried on continuously in order to improve and cheapen existing products and to evolve new products. Much of this work is very closely allied with engineering activities and largely done by the engineering staff. Other forms of research are best carried out by physicists, chemists, and other specialists, who can work in suitable environment apart from the regular technical activities of an engineering department. The chief ingredients of a research laboratory are the personnel and the equipment, and if these are right the product will be worth the expense involved. Much of the work even in a research laboratory is of a straightforward or routine kind, but other work will be of a distinctly pioneering and original nature. Ideas in the early stages are usually plentiful; and careful judgment is needed to decide which of these ideas are likely to be valuable and should be followed up, as there is always much work to be done before a new idea can be transformed into a tangible product. In addition to making these decisions, the head of a research laboratory must exercise skill in the choice of his staff and in arranging that each man is doing work which is best suited to his particular ability. He must keep in touch with contemporary literature and the work done by the laboratories of other manufacturing organizations and the large universities, and also by our own Electrical Research Association. This last Association has the personnel, but until recently it lacked the equipment and environment that the laboratories of the large companies and universities possess, and was therefore dependent to a great extent on these latter facilities. As you know, the E.R.A. is supported financially by all branches of the electrical industry and has done much good work, and is well placed for research into many problems of general interest to the industry.

From the above incomplete remarks it will be seen that the supplementary technical activities of a manufacturing organization are quite extensive, and of importance not only to itself but to the whole industry.

CIRCUIT INTERRUPTION

Having said so much of a general nature I should like to deal now with the two problems to which I have already referred, namely circuit interruption and voltage impulses. In doing so I have attempted to review their present state, and I have not given any detailed conclusions as these are best dealt with in specific papers.

In order to have proper control of any electric circuit it is necessary to be able to open or close this circuit reliably. In the usual constant-voltage circuit a fault generally gives rise to a large increase in current. It should be possible to make and break the circuit under the emergency conditions caused by a fault. When a fault occurs it is desirable to be able to open the circuit in the briefest possible time, so as to localize and minimize the damage caused to the circuit, or to any apparatus connected to it, and to prevent synchronous machinery falling out of step, due to loss of synchronizing power whilst the voltage is low. Interrupting a direct-current circuit is more difficult than interrupting an alternating-current circuit; but fortunately it is not often necessary to interrupt large d.c. circuits. The current in large d.c. plants such as rolling-mills, mine hoists, etc., is controlled by manipulation of the field circuits of the machines, and generally it is only in traction circuits that large direct currents are broken. Here it is usual to employ very high-speed breakers which can open the circuit before a short-circuit current has reached full value. The arc is blown out magnetically and the whole operation, from the commencement of the fault until the circuit is broken, occupies only a few thousandths of a second. The amount of inductance in a d.c. circuit is independent of the power in the circuit, and, if large, may cause high voltages to appear when the circuit is broken rapidly. This high voltage increases the arcing between the switch contacts and may cause breakdown of the insulation somewhere in the circuit. Fortunately, in traction work any circuit broken is usually one of several, and the presence of the others mitigates these difficulties.

Although interruption of a.c. circuits is inherently easier than that of d.c. circuits, this is only a relative statement; and due to the growth in size and the interconnection of a.c. power systems the proper operation of circuit breakers is one of the major problems that engineers have to solve. Fortunately, our knowledge of this subject has increased greatly during the last few years as the result of an enormous amount of research and experimental work, accompanied by a large expenditure in making models, and apparatus for testing them. These are three main reasons why it is easier to interrupt a.c. than it is to interrupt d.c. circuits. Firstly, the current momentarily becomes zero at the end of every half-cycle; the arc goes out, and an opportunity occurs to prevent it re-starting. Secondly, the amount of reactance is associated with the amount of power flowing; it is therefore limited and usually lower than in d.c. circuits. Thirdly, the rate of change of current, which in conjunction with the reactance in the circuit determines the voltage across the arc, depends almost wholly on the mechanical rotation of the heavy masses of the generator, and, to a very limited extent only, on the manner of operation of the circuit breaker. On account of these conditions research and practical experience indicate that the problem of a.c. circuit interruption is best solved by concentrating on prevention of the re-striking of the arc after its extinction at the end of a half-cycle. They also indicate that the contacts should be oil-immersed and should separate at a definite but not too rapid rate, depending on the voltage of the circuit.

The sequence of events in circuit interruption in ordinary oil circuit-breakers such as are fitted in the less important circuits of most power systems to-day is as follows: The relay operates, usually as a result of abnormal current due to a short-circuit; this trips the breaker and causes the contacts to part. All this takes several cycles, and one of the modern improvements consists in designing relays, trip mechanism, and switch mechanism, so as to reduce this time. When the contacts part an arc appears between them; this arc is comparatively short and has low resistance so that the current continues to flow as if there were still metallic continuity between the contacts. The high temperature of the arc fills the space between contacts with metallic vapour and ionized gases which are formed by dissociation of the oil and make this space conducting. The sudden formation of gas gives rise to a pressure which is transmitted through the oil and resisted by the tank of the breaker. At the end of half a cycle the arc ceases. The path is still hot and conducting, but is rapidly de-ionized due to cooling and also to turbulence of the gases and oil. As the power factor of the circuit is usually very low, especially under short-circuit conditions, the voltage across the breaker, which was zero when the breaker was closed, tends to rise to full normal value immediately the arc ceases. If it rises sufficiently rapidly, and the path between contacts is still conducting, the arc will be re-established and will continue for another half-cycle, with further evolution of gases, etc., but with greater intensity, as the arc is now longer, due to the motion of the movable contacts. This process usually continues for several cycles, until, due to the increased distance between contacts and the de-ionizing effect of the greater turbulence, the resistance becomes too high to allow the available voltage to re-establish the arc, and the circuit is interrupted. If the arc is re-established too often the pressure due to gas formation may be great enough to burst the tank. The failure of a large oil circuit-breaker can be a serious disaster, and the breaker is usually placed in a flame-proof cubicle to prevent any damage spreading.

The manner in which the voltage is re-established across the circuit breaker when the current passes through zero, or the rate of rise of the restriking voltage, as it is called, has an important influence on the operation of the breaker, and has been studied with the aid of the cathode-ray oscillograph. This rate is found to be very rapid and to be associated with the characteristics of the circuit to which the circuit breaker is connected. The higher the electrostatic capacitance, the slower the rate, as time is required to charge the circuit if it has considerable capacitance. In practice, circuit breakers far from the source of supply operate more easily than those nearer the power station, due to the greater electrostatic capacitance between them and the source of supply. The exact relationship between rate of rise of the re-striking voltage, the operation of the circuit breaker, and the characteristics of the circuit, is not yet fully understood, although much research has already been done. The work done on the circuit breakers themselves has consisted in devising means for making the space between contacts non-conducting as rapidly as possible after the arc is extinguished. If this can be done more rapidly than the voltage is re-established, then the arc will not restrike. Results have been so successful that large circuit breakers have already been built in which the arc duration is only one half-cycle of current. Such a breaker can open a circuit with very little distress, as the amount of energy in the arc during this short period is comparatively small. Means of controlling or extinguishing the arc must either be sufficiently powerful to do this under all conditions or must be variable and proportional to the arc intensity. If the means employed are too powerful the arc may be blown out under light-load conditions before the circuit reaches the end of the half-cycle. Such a condition is liable to give rise to a dangerous over-voltage, instead of the double voltage limit which occurs if the current ceases in the normal manner.

HIGH-VOLTAGE TRANSIENTS

The other problem that I should like to talk about is the avoidance of failure from transient high voltages. According to the British Standard Specifications, machines and apparatus are given a high-potential test at standard frequency, generally twice the normal voltage plus 1 000. If the apparatus is well made, and not maltreated afterwards, such a test should be ample to guard against any high voltage at generated frequency, because it is not usually possible to get an over-voltage of more than about 25 per cent. Saturation of the generator and transformer will prevent a higher value. There are other voltages of very short duration, generally known as impulses and surges, that may cause breakdowns for two reasons. Firstly, these transient voltages may rise to a very high value; and secondly they are of such short duration that they cause local concentration of voltage at some point in the winding and large difference of potential between parts which normally are at approximately the same potential and are not highly insulated from one another.

Such an impulse at the terminals of a transformer may cause a high potential between the end turns. An instant later the concentration of voltage will have travelled towards the middle of the transformers and caused stresses in the insulation between turns there also. An impulse usually rises to its full voltage in about 1–5 microseconds and then gradually falls away, the total time being about 50–100 microseconds. If the discharge flashes over an insulator or protective gap it will probably do so before it attains its maximum value, and in that case dies away very quickly; the whole time may be only 2–3 microseconds. This is known as a chopped wave. The original impulse, as it penetrates through the winding, changes and takes the form of a train of waves of gradually diminishing amplitude. The chopped wave gives rise to higher voltages between end-turns, but to less severe oscillation in the body of the winding. It is usually feasible and sufficient to use adequate insulation not only between windings and earth but between individual conductors; this, however, becomes increasingly difficult with higher voltages. If the impulse is concentrated in the end windings then the rest of the insulation is momentarily unemployed.

The distribution of voltage due to an impulse depends on the electrostatic capacitance of the windings to one

another and to earth. By suitable arrangements of the windings local concentration of the impulse voltage can be avoided or reduced. For example, if the windings are arranged in concentric layers with a voltage shield connected to the high-voltage terminal on the outside, then the layers form a number of condensers in series and the impulse voltage will be divided up between them and the whole of the insulation will be utilized to resist the shock. In another arrangement, if shields are so fitted that they have capacitance coupling with the various parts of the winding in proportion to the voltage normally existing in these parts, then there will again be no momentary concentration of voltage and the insulation will be uniformly stressed.

There are two usual causes of surges or impulses—switching and lightning. As already mentioned, opening a circuit breaker may produce a momentary voltage-rise of twice normal value, but the energy associated with this is usually small and is soon dissipated. Under certain circumstances higher impulses may occur, but these are exceptional so that normal switching operations should not cause trouble, and this is confirmed by experience. The chief cause of impulses is lightning. Here the energy may be large, the voltage is almost without limit, and the current may have a maximum value of 100 000 to 200 000 amperes. In measuring the value of the discharge current several ingenious arrangements have been used. One consists in placing small pieces of steel near the conductor carrying the discharge. The magnetic field of the lightning discharge magnetizes the steel and from the extent of magnetization the current can be deduced. Another method is to place a small tubular conductor in the path of the discharge and determine the current from the crushing of the tube due to the electromagnetic forces. Several manufacturing firms have provided themselves with equipment for producing artificial lightning discharges and with the aid of a cathode-ray oscillograph have studied the effect of surges on various types of apparatus. Although other theories were held at one period, it is now generally agreed that it is only the direct stroke that causes damage. At the point where the stroke occurs there may be a current of 100 000 to 200 000 amperes to conduct to earth, and a voltage against which it is impossible to insulate. A short distance away the voltage will be limited to the flash-over value of the line insulators, and the current to that value which this voltage can force through the surge impedance of the line. To protect a line from a direct stroke it should be enclosed in a well-earthed Faraday cage—the practical form of which is the overhead guard-wire. At one time there was considerable difference of opinion as to the value of guard-wires, but that arose before it was realized that guard-wires can only be effective if well earthed. For example, if the resistance of a tower to earth is 10 ohms and the current in a lightning stroke is 100 000 amperes, the potential of the tower may rise momentarily to a million volts and a flash-over will occur from tower to line—the line even at normal voltage being comparatively near earth potential. I have had personal experience of an occurrence which supports this theory. A line consisting of two high-voltage circuits and two low-voltage circuits carried on steel towers was struck by lightning. The flash-over occurred on the low-voltage line, although this was underneath both the high-voltage line and a guard-wire. In the immediate neighbourhood of expensive transforming or switching apparatus the guard-wire arrangement should be very efficiently carried out, so as to avoid damage from direct strokes. The spark-over value of the line insulation should be reduced below that of the connected apparatus, in order to deal with impulses arriving from other parts of the line. This may be done by means of plain gaps or lightning arrestors. The lightning arrestor has the advantage that if properly designed it will prevent the power arc that may follow the impulse. It must be capable of withstanding the voltage and also absorbing the current of the impulses. A device known as the Petersen coil has been used extensively on the Continent for ensuring continuity of supply. This does not reduce the value of the impulse voltage but prevents the power current following. The neutral point of the system is connected to earth through a reactance. A flash-over between one phase and earth will earth the system at this point, and will initiate a power arc. The voltage to earth of the other two phases will increase and give rise to a capacitance current through this earth point of such a value as would ordinarily be sufficient to maintain the arc. The voltage of the neutral point also rises and causes a magnetizing current to flow through the reactance. These currents will be approximately in opposite phase so that if made nearly equal they will give at the earth point a resultant current insufficient to maintain the arc and consequently it will go out and the system be restored to its normal state. Another method of conducting the lightning stroke to earth and preventing the power arc from following is to enclose the spark-over gap in a suitable tube. The tube has openings through which the gases from the power arc escape and in doing so form a blast which effectively extinguishes the arc. These expulsion gaps can be used in systems where the neutral point is earthed.

I have attempted to review two problems which I believe to be of considerable interest to many of us at the moment, but in the scope of a Chairman's Address the review is necessarily brief. I hope, however, that what I have said will indicate roughly the present state of the progress in both these problems and will form an introduction to other papers, which I know will follow in the near future, written by specialist members of our Institution.

NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By E. C. McKINNON, Member.

"THE BRITISH ACCUMULATOR INDUSTRY"

(ABSTRACT *of Address delivered at* MANCHESTER, 22*nd October*, 1935.)

Last year marked the centenary of the birth of the inventor of the lead storage-battery, a French scientist, Gaston Planté.

The complete history of the invention of the lead-acid battery has been written in book form so frequently that it would be redundant to repeat it once more. Moreover, it is a very long story, the synopsis of which is as follows:

Gaston Planté, as a result of experiments, and research work commenced in 1859, discovered that the polarization of all the ordinary metals could be achieved by passing an electric current through an electrolytic cell containing these metals as electrodes. Every one gave secondary currents, but those obtained with lead electrodes in dilute sulphuric acid gave far superior results over all others, both in duration and intensity. Planté was, however, working under a severe handicap as the modern dynamo had not then been invented. He rendered his electrodes active by passing an electric current through them first in one direction and then in the opposite direction, thus gradually building up lead peroxide on the positive plates and spongy lead on the negative plates. For this purpose he had to employ primary batteries, which had been known and used for some time previously.

In 1881 another Frenchman, Camille A. Faure, discovered another practical form of storage battery, which he patented, covering the preparation of active material of lead storage cells from lead salts and applying these mechanically to the surface of the electrodes. For several years from that date numerous inventors proposed modifications and improvements, but the fact remains that after 54 years the two principles of Gaston Planté and Camille Faure constitute the basis for the design and construction of all present-day lead-acid cells.

Planté was only 25 years old when he made his great discovery. I do not consider that this indicates that the young men of that period had greater perspicacity than the young men of to-day, but in those days there was still so much to be discovered that even a young man could hope to acquire much honour and glory from his research work without spending almost a lifetime in evolving some momentous invention.

It is particularly important to note that, although Planté made his invention about 1860, its commercial development did not take place until several years afterwards, and for a very good reason—neither the dynamo nor the electric lamp had yet been discovered.

Records show that an electric glow or incandescent lamp was invented by Swan in 1878, and another type was evolved by Edison in 1879.

Siemens invented the dynamo-electric machine in 1867. Edison followed with a dynamo simpler in form than that of Siemens in 1879, and Dr. John Hopkinson patented the Edison–Hopkinson dynamo in 1883.

The storage battery—the dynamo—the incandescent lamp—all were brilliant discoveries individually, but it was the combination of the three which enabled the value of each to be utilized to the utmost extent commercially and paved the way for the building-up of three huge industries.

Thus when lighting by electricity could be contemplated as a practical achievement, the storage battery was available as a reservoir from which to maintain the light when the generating plant was shut down. Very soon, however, it was found more convenient to employ the battery as the main source of supply and replenish its charge during periods when lighting was not required. This latter condition applied especially to private installations, but even in public supplies of considerable magnitude it was quite normal practice for several years for the lighting generators to be run only a few hours out of the 24, relying upon batteries to maintain the supply for the remainder of the period.

Let us remember that even in 1890 very few towns had a public electric supply. There were no electric trams; there were no turbines; trains were illuminated by oil or gas; there were no submarines; there was no self-starting equipment on motor-cars; there were no motor-cycles, no aeroplanes, no wireless, no cinemas.

The extent to which the storage battery has rendered practicable the commercial development of so many new electrical applications is perhaps not appreciated nowadays. To mention only a few, apart from domestic and municipal electric lighting and power, the list includes: electric tramway schemes; submarines, telephones and telegraphs; electric lighting of trains; starting, lighting, and ignition of automobiles; wireless transmission and reception; electrically propelled vehicles; cinema sound transmission; miners' electric handlamps; and aircraft.

In a review of this nature it is useful to trace out the early history and development of the applications which now constitute the main lines of battery absorption.

Tramways

The first electric tramway system, or one of the first, was inaugurated in Berlin in 1881, but it was not until 1895 that municipal electric tramways were put into operation in this country, Bristol being the first town.

The trolley electric trams emerged successful from a series of competitive systems designed to supplant the original horse-drawn trams. Steam-propelled trams, cable cars, surface-stud system and battery-propelled trams had all been tried out, but during the last 10 years

of the past century the electric trolley car became almost universally standardized.

The steam engines in use in the new era of electric tramways were not capable of coping with sudden heavy loads. Some relief was gained by placing so-called buffer batteries across the generator bars, but in 1897 J. S. Highfield invented an automatic reversible booster which acted as an automatic means of levelling the load on the steam generators, peaks in the load on the station busbars being fed by a storage battery, and dips in the load being filled up by charging the battery.

Submarines

The evolution of the modern submarine was necessarily in step with the perfecting of the storage battery. No satisfactory source of power for propulsion of the vessel under water, other than the storage battery, has yet been devised. The battery also supplies all the energy for lighting, heating, and cooking, when the vessel is submerged.

The building of the first British submarine was commenced at Messrs. Vickers' Works, Barrow-in-Furness, in 1901, in execution of an order from the British Admiralty for five boats towards the nucleus of a fleet of submarines. The five submarines in question had an overall length of 64 ft. and a displacement of about 120 tons, of which the batteries accounted for 30 tons. So little confidence had the battery maker's construction staff in the ability of the first submarine to continue to float if loaded with the 30 tons of battery that they refused to go on board to install the battery until chains were passed round the submarine and she was held poised at surface-level by an overhead crane. These boats were entered as of the "A" class, and they were succeeded in alphabetical progression until the "S" class has now been reached. A submarine equivalent to the "R" class has an overall length of about 290 ft. and a displacement of about 1 500 tons, the battery weighing about 150 tons. For this increased weight the total battery kilowatt-hour capacity has been increased more than ten times. Boats of still larger displacement have since been built.

Telephony

The public telephone system adopted in this country by the National Telephone Co. was that developed by the Western Electric Co. in the United States. It is known as the "common battery" system, in which a central battery supplies the energy for both talking and signalling at the stations and also at the switchboard.

The first common battery exchange opened in this country was at Bristol in May, 1900. Incidentally this was also the first C.B. exchange in Europe. Mr. L. E. Wilson, a member of this Centre, was responsible for the erection of a number of the earliest exchanges.

The total number of C.B. exchanges in this country at the end of March last was 455, and I am told by Mr. T. E. Herbert that the total number of stations connected to these exchanges was 990 329 out of the total of 2 359 811 existing in the country.

The successful results obtained with the common-battery telephone system were due essentially to the extremely low internal resistance of the lead-acid storage battery.

In 1911 the National Co. was taken over by the Post Office, but an option was granted to certain municipalities to take over the telephone services on payment of an annual sum to the Post Office. This privilege was accepted by Hull Corporation, and a municipal telephone system has been maintained at Hull ever since.

In 1912 the first automatic exchange in this country was opened at Epsom. With the introduction of the automatic telephone system the average size of the batteries required at each exchange was greatly increased. In a number of instances the battery capacity is 20 000 ampere-hours per exchange, provided by two batteries each of 10 000 ampere-hours capacity.

Wireless Telegraphy

Wireless telegraphy is associated closely with Marconi, who commenced his first experiments in Italy in 1895 and gave demonstrations to the British Post Office officials in 1896, first over a distance of 100 yards and then over $1\frac{3}{4}$ miles. Improvements were perfected so rapidly that transmission was effected between Bath and Salisbury, a distance of 34 miles, in 1897, and in 1901 Marconi received the famous "S" signals from Poldhu at St. John's, Newfoundland. In 1902 signals from Poldhu were received by the s.s. "Philadelphia" 2 100 miles away, and in 1912 Marconi was obtaining regular communications between ships and Ireland over a distance of 4 000 miles by day and 7 000 miles by night.

Eventually various countries, notably Great Britain and the United States, made compulsory laws that every vessel had to be equipped with a wireless telegraph system, and an auxiliary power supply independent of the vessel's main electric power plant must be provided which would enable messages to be sent over a distance of at least 100 miles, day or night, for at least 4 hours. The equipment included storage batteries to supplement the main source of electric supply required for transmission and reception.

The first important occasion when the value of marine wireless telegraphy was proved followed a collision between the s.s. "Republic" and the s.s. "Florida" on the 23rd January, 1909, 35 miles from Nantucket lightship. As a result of wireless messages sent out by the operator while the "Republic" was slowly sinking, nearly 2 000 lives were saved. It was a great triumph for wireless.

Wireless Telephony and Television

The first prearranged transatlantic wireless telephone conversation between New York and London was carried out with the aid of batteries in 1923.

In 1927 Mr. J. L. Baird brought his discovery of television to a sufficient pitch of perfection to enable him to carry out television transmission from London to Glasgow by the aid of storage batteries for high- and low-tension supply.

Automobiles

Electric self-starters for automobiles employing storage batteries were developed in 1911. Previously batteries

had been carried on automobiles for electric ignition and lighting, but certain builders decided to provide a battery powerful enough to crank the engine by means of a small motor. The earliest batteries fitted to cars for this purpose were so robust that many lasted more than 10 years, but, later, car builders considered that price and weight in particular were of far greater importance than great durability, and much lighter batteries became standard practice.

Talking or Sound Pictures

The first commercial attempt at talking pictures was made with the introduction of the "Cinephone" in 1908, this being a gradual evolution from the Zoopraxoscope produced by Edison and Muybridge in 1866, the Chronophotophone, comprising pictures combined with a voice from a phonograph, demonstrated by Demeny in Paris in 1892, and a patent taken out in U.S.A. in 1899 for a combination of phonograph and cinematograph, using a method of synchronization for keeping the two in step.

Although synchronized speech and picture machines were employed in 1910 to 1911, no commercial interest was taken until the production of the thermionic valve for wireless.

Flight

At the outbreak of the War in 1914 Great Britain had about 80 aeroplanes, this number being increased at the time of the Armistice in 1918 to 25 000. In 1919, successful non-stop flights were made across the Atlantic.

Airships also had developed to such a stage that the British Army Airship R 34 made the Atlantic crossing in July, 1919, and in August, 1930, R 100 flew from Cardington to Montreal, covering 3 400 miles in 79 hours.

In 1927, Imperial Airways, Ltd., inaugurated a scheme for linking up the British Empire by air.

Every machine is equipped with storage batteries for various purposes.

The Storage Battery in Time of War

It is perhaps an unhappy reflection that without storage batteries modern warfare would be robbed of much of its ruthlessness. At the Battle of Waterloo in 1815 not a single electrical device was used. During the Great War of 1914–1918 storage batteries were either an absolute essential or a beneficial addition to the electrical equipment of the following: Central stations, munition works, fortresses, hospitals, telephone exchanges; men-of-war, submarines, lightships, hospital ships, Red Cross trains; airships, aeroplanes, automobiles, electric locomotives for shunting and mining, and electric runabouts.

The duties to which batteries were put during the War were countless, the following being only a few: Propulsion, heating, lighting and cooking for submarines when submerged, gun-firing control, torpedo discharging, range finding, searchlights, mine firing, magazine hand-lamps, field telegraphs, cauterizing, portable lighting by lamps and torches, train lighting, self-starting, and coil ignition.

Marine Duties

About the year 1931 automatically operated standby power for steering and lighting seagoing vessels became a recognized feature of marine design.

Batteries serve the following applications on a modern turbo-electric liner, in addition to the standby power mentioned above: Wireless installations, including short-wave and broadcasting receivers, gramophone repeaters, talkie cinemas, intercommunication telephones, lifeboat wireless equipment, electric clocks, electric fire detectors, loud-speaking telephones, and submarine signalling.

Remote Control in Substations

The first entirely remote-controlled d.c. substation in this country was put into service at Hull in 1925. From the main station all operations at the substation could be controlled—the closing and operation of circuit breakers; paralleling or disconnecting a 3-wire 6 600-ampere-hour battery; and raising or lowering the voltage by remote control of the battery end-cell switches.

The Grid

In 1926 an Electric (Supply) Bill was passed by Parliament concerning a Government National Scheme, later known as the "grid," for the standardization and interlinking of public supply electrical undertakings. The adoption by the Electricity Commissioners of alternating current as the standard for distribution led some people to imagine that the knell of batteries was sounded. On the contrary, the Central Electricity Board during the following few years placed large orders for storage batteries for various applications associated with the grid.

Trickle-Charging

For many years it was regarded as an axiom in storage-battery management that to keep a battery healthy it must be given frequent charging and periodical artificial discharges if ordinary working conditions did not call for any appreciable percentage of the battery's rated output.

With the advent of standby batteries trickle-charging was introduced and first applied to a large stationary emergency battery at the Bankside power station of the City of London Electric Supply Co. in 1927.

The theory of trickle-charging as a method of controlling the standby battery is that if the open-circuit loss of battery capacity be just balanced by an equal amount of charge, fed continuously into the battery, the condition of the cells will remain unchanged indefinitely.

The accuracy of this theory was proved and established by the fact that when the plates in the Bankside battery were examined after 7 years' standby service under continuous trickle-charge control, they were found to be equal to new, and, what is still more important, the battery was then demonstrated to have its full rated capacity without any artificial treatment or preliminary charge and discharge cycles.

The Situation To-day

This brings us up to the present time, and what do we find to-day when reviewing the British accumulator industry 75 years after its inception?

First of all, the long list of those companies who have engaged in the manufacture of lead-acid storage batteries in this country would appear to afford a good example of the survival of the fittest, which with sundry newcomers makes a total of about 10 existing companies.

The alkaline-cell section of the accumulator industry has made considerable strides in recent years, whereas formerly their application was confined almost entirely to traction purposes, and at least four accumulator makers in this country manufacture alkaline batteries.

Very important economic changes have been made, influenced to some extent by Government tariffs and quotas. One most striking example is the case of Australia. Whereas formerly lead was brought from Australia to England and shipped back to Australia as storage batteries, replicas of the best English types of battery are now manufactured in Australia under the supervision of English-trained engineers and chemists.

The design of stationary storage batteries has not altered very materially for several years past. Battery makers came to realize that patented components did not necessarily inflate sales. Competition automatically tended to bring batteries to a common basis as regards weight, dimensions, and capacity. The introduction of sealed-in stationary cells which could be transported to an installation in a fully charged condition is one of the outstanding improvements in recent years.

The evolution of batteries which, by special preparation in manufacture, only required a short first charge was another step forward in progress leading to the perfection of so-called "mass-type" cells, which could be put into service without an initial charge merely by filling with acid.

In radio batteries design has been somewhat fortuitous. Designers of wireless sets have been prone to complete their design and then call for a battery which must give a specified capacity and must fit a special-size compartment without any regard to the natural characteristics of a battery.

The evolution of the submarine battery in 35 years has been such that, while the average life has increased by nearly 200 per cent, the watt-hour capacity for given volume has also been trebled.

Research has enabled many anomalies to be removed as regards relative dimensions of electrodes, volume of electrolyte, and declared capacity ratings, and has led to enhanced endurance and durability.

Durability is liable to recoil on the battery maker. No one has yet explained with satisfactory reasons what should be regarded as a reasonable life for a battery. For instance, recently a battery was discovered in a remote part of Ireland still working satisfactorily at a country-house installation after 36 years' service. This is not good publicity, for if everyone expected 36 years' life from his battery there would be no renewal orders for the battery companies and no dividends for the shareholders.

In passing it may be mentioned that one suggestion proffered for the abnormal longevity of this particular battery was that the Irish battery attendant could not understand English technical terms and therefore had not been able to follow the battery maker's instructions!

Designs

Since the first automobile starter battery came into service in 1911, numerous current-consuming appliances have gradually been added to the electrical equipment of a car, but despite these the present-day starter battery weighs much less than the original model, occupies less space, and yet gives a long life.

The evolution of aero machines has called for much ingenuity in the design of storage batteries. In fact, the aeroplane battery and the submarine battery have so many interesting points of design that a little descriptive detail is justified.

Naturally both types have to be compact in proportion to their rated capacity, but it is essential that the submarine battery shall have great durability in order that the efficiency of the submarine as an offensive or defensive unit shall not be impaired by a drop in battery capacity or the need for frequent battery renewals. A submarine cell is not an article which can be easily man-handled; the size and weight, of course, vary with capacity, but the capacity of a single cell may be as much as 15 000 ampere-hours and the weight as much as 1½ tons. Such a cell would have a volume of about 19 cub. ft., and each of these units, which may number from 100 to over 300, has to be lowered intact into the submarine.

The aeroplane battery by comparison is a featherweight design and in the case of military machines it must be absolutely unspillable in the inverted position to meet the demands of aerobatics. The output of an aeroplane battery in proportion to its size and weight may appear incredible. A military aeroplane battery may have a rating of 430 watt-hours in 10 hours at 11½ volts, in which case its weight would be about 46 lb. and its volume about 740 cub. in. Such a battery would give a discharge of over 1 100 watts for 5 minutes, and would yield 9¼ watt-hours per lb. at the 10-hour rate.

The Battery as a Public Benefactor

Although I have indicated earlier in this address the utility of the battery as an engine of war and thereby as a destroyer of human lives, it must be admitted that the storage-battery saves many lives on land and sea. One cannot overlook the immense security afforded to patients and surgeon alike during the performance of hazardous operations in hospital when there is a storage-battery emergency-lighting equipment to ensure continuity of the all-important light.

Many lives are saved at sea through electrically equipped lifeboats and through the assistance forthcoming in response to SOS signals by wireless transmission.

The storage battery is also a benefactor to countless wireless users who are as yet unable to employ a mains-driven set, although it is a matter of opinion whether they would be wise if they rejected the far more agreeable battery-driven set even if a main supply were available.

To the motorist, especially if the engine be stubborn, the storage battery is indispensable, whether he has a weak heart or an inborn dislike for doing hard work.

In coal mines millions of workers appreciate the amelioration of their working conditions by the provision of more adequate illumination, which is rendered possible by battery headlamps.

The telephone user also has to thank storage batteries for providing him with a dead-silent background to his reception without any tantalizing cross-talk or irritating commutator hum.

The railway traveller is unable to notice any difference in the intensity and steadiness of the electric illumination whether the train be in motion or at a standstill, although in an article in the *Children's Encyclopædia* one can read that " when the train comes to a standstill the lights are then fed from a storage battery and that is why they seem brighter!"

Various Present-Day Applications

The invention of the steam turbine terminated the general employment of storage batteries and reversible boosters as load regulators in tramways and other power stations where wide load fluctuations were otherwise uncontrollable.

The gradual scrapping of the electric tram and the substitution of the bus, together with the ever-increasing fleets of motor coaches and heavy commercial vehicles surging along our highways and byways, has created a need for large portable lighting and power equipments complete with storage batteries.

The natural inevitable universal adoption of electric lighting of railway coaches creates a demand for more and more batteries. At least one of the leading British railway companies has adopted electric cooking on the kitchen cars of long-distance expresses, utilizing storage batteries as the source of supply.

Electrically propelled commercial vehicles are bound to be the ultimate method of transport in our cities and large towns. Until quite recently this form of transport had not made any rapid headway comparable with that recorded in other countries, America in particular. For many years the commercial electric vehicle business in this country was mainly exploited by American companies, and it is possible that American models did not have sufficient sales-appeal to British users.

Steam wagons also have been allowed a freedom (perhaps to too great an extent) of the streets and roads.

The correct types of battery for road traction have been available for some time, and headway appears to rest on improvements in the design and efficiency of the vehicle and its electromotive equipment. Very evident signs of headway are now forthcoming. British manufacturers have taken up the design of commercial electric vehicles on progressive modern lines, and to-day the retail traders are vying with each other in their enthusiasm for this clean and economical form of transport.

To illustrate the progress that has been made in the design and manufacture of vehicle batteries it may be mentioned that the average working life of present-day batteries has been increased by 4 and even 6 times that of earlier batteries.

One of the widest applications for batteries nowadays is for emergency and standby purposes in many forms. Dislocation of business, such as a black-out during the winter sales or Christmas shopping period, leads to special investigations by the disconsolate traders. The battery maker naturally can point out that a storage battery is synonymous with assured continuity of illumination. It is realized, of course, that continuity of supply is of the highest importance. In the case of the grid this continuity is aimed at by interlinking various generating stations, but the vulnerability of the overhead mains spread over the countryside is self-apparent. If a falling plane can dislocate the lighting, power, or transport, over a large territory, or if the breakdown of one super-unit can suspend industry and social relations over a wide area for a period measured not in seconds but in hours, the policy of shutting down so many producing stations is open to criticism.

I am not supporting the installation of £1 000 000 storage batteries advocated by a past Chairman of this Centre in his address a few years ago, but I maintain that a very strong case can be made out for de-centralization in the interests of the nation in times of peace or war—especially the latter. By this I mean the multiplication of small stations eked out normally by a national grid, but self-contained for times of national emergency, and in each case complete with a storage battery as an unfailing security.

Even though the storage battery has been ousted from its previous position in the majority of British central stations, it still appears as an important component of substation plant, in which it functions primarily for remote switch control.

It may be of special interest to note particular applications for which storage batteries have been installed in central stations and large electricity works during recent years, that is since the conception of the grid.

Station " A." Emergency Work.—The battery is brought into commission to maintain supply to all current-consuming devices inside the station during temporary dislocation. Between these occasions the battery is maintained in a fully charged condition by a modern method of trickle-charging.

Station " B." Winter Peaks.—The battery has been installed to augment the total station capacity during the winter evening peak demands as an alternative to putting down additional boilers and machines.

Station " C." Standby.—The battery serves as a supplementary power and lighting unit when storms, floods, and ice, disturb the incoming hydro-electric supply.

Station " D." Bulk-Supply Economy.—The battery is installed to reduce the maximum demand on the grid mains at the particular station, thus keeping down the grid charge for supply to that station.

Station " E." Continuity of Power Supply.—This is a large private power station taking public supply, where a stoppage in the supply would entail a serious loss of the products in course of process. The battery installed is assumed to have a capacity adequate to cope with an interruption in the public supply in excess of the most pessimistic forecast of such contingency.

Station " F." Safety of Public.—A private substation (taking public supply) serving a building where a black-out might cause panic amongst those present. A battery has been installed to take over the supply in the event of a breakdown.

Station " G." Insurance against Pilfering and Larceny.—A private substation (taking public supply) serving a super-store. Sufficient pilot lights to illuminate all

departments are fed from a battery operating on an automatic equipment scheme for emergency lighting.

From these instances it will be seen that there are at least seven distinct varieties of heavy and important duties served by batteries in central stations and electricity works.

Other specific duties of batteries in power and substations include: (1) Supplying power to auxiliary motors, pumps, switches, etc., when their normal supply is interrupted; (2) Supplying current for limited emergency lighting; for closing solenoid- or motor-operated h.t. switches; for tripping out these and other switches; for indicator lamps; for indicating and signalling relays; for supervisory control system; and for metering.

Inspection and Control

Important advances have been made in the simplification of inspection and means for gauging at sight the condition of a battery—a very useful convenience in the case of substation batteries.

The method of controlling batteries has also undergone material change in the course of years. Perhaps the most important is the development of trickle-charging within the last decade.

Trickle-charging has reduced the operation of substation batteries to extreme simplicity. It renders periodical artificial discharges or prolonged charges unnecessary, and although trickle-charging primarily compensates for open-circuit losses in a battery it may also be employed to balance out intermittent short discharges such as are required for switch operation.

Central-station engineers will appreciate the advantages accruing from this feature, both in saving of time and cost of service and the increase in the efficiency of a substation, if it is unnecessary to remove the battery periodically to headquarters for a recharge or other service.

Trickle-charging is not synonymous with the floating of a battery, i.e. one which is floated across the mains fed from a d.c. supply. To be immediately responsive to variations in voltage, such batteries must be kept about three-quarters fully charged, whereas a trickle-charged battery is kept fully charged, i.e. entirely de-sulphurated.

Standardization

Serious attempts have been made by the battery makers to secure recognized standardization and thereby mitigate the burden of carrying huge stocks of all sorts and sizes of plates. Standardization, however, as applied to storage batteries, is extremely elusive.

Under the auspices of the British Standards Institution a representative committee, including battery makers, Government Department officials, consulting engineers and supply engineers, met and in due course prepared B.S.S. No. 440 for stationary storage batteries, and B.S.S. No. 439 for portable accumulators.

Inquiries from overseas do occasionally call for batteries to the former specification, even if the local conditions preclude its application, but it is a remarkable fact that consulting engineers and Government Departments at home still draw up their own special specifications, as if the British Standard Specifications were non-existent.

Even the members of our Institution are not above reproach in their disregard of standards and conventions. For instance, within the past few weeks an inquiry was issued by a city electrical engineer for the supply of batteries. The actual specification was restricted to 40 words, but the accompanying general conditions covered four pages of foolscap. Forty words cannot convey much in the way of a specification, and even the capacity required was omitted in this instance, it merely being stipulated that the cells must be capable of giving a stated current in amperes—time not mentioned—without detriment to the plates. This contempt for standards is only one of the factors which account for the astounding number of various types and sizes of plates manufactured to-day. The total number of distinctly different plates turned out by one firm alone exceeds 900.

Modern Works Methods and Personnel

From the works point of view the most striking change from early methods of producing storage batteries is the modern mechanization of so many of the processes in the production of small batteries for automobiles and wireless work. This has been carried to such a stage of perfection and completeness that over-production has to be closely avoided.

Another change is the demand for greater technical or scientific qualifications in the selection of the personnel. A small battery company may perhaps still make good with one or two technical men possessing a smattering of chemistry and a fair knowledge of electrical engineering, but the organization of a large modern battery company includes duplicated staffs of scientists, metallurgists, analytical and research chemists, electrical and mechanical engineers, mathematicians, designers, electricians, and testers.

On the commercial side the sale of storage batteries must not be compared with that of electrical accessories. It is a specialized vocation and art, calling for an engineer's training and practical experience with a thorough grasp of the innumerable current-consuming devices served by storage batteries.

One battery sales engineer may have to deal with multitudinous applications of batteries for marine purposes, including submarines, steering control, gyroscopes, torpedoes, and ship's wireless, etc. Another may have to be *au fait* with all that pertains to bus-lighting equipment, and yet another may have to handle widely varying schemes concerned with emergency equipment.

The Future Outlook

At no time within the last 30 years has the outlook for the British battery industry appeared brighter than at present; at no time has the storage battery been so indispensable or its application so universal; and at no time has the industry possessed such a wealth of scientific and technical knowledge of that most baffling offspring of necessity—the storage battery.

SCOTTISH CENTRE : CHAIRMAN'S ADDRESS

By J. B. MAVOR, Member.*

(*Address delivered at* GLASGOW, *29th October*, 1935.)

As the technicalities of my job are of a somewhat restricted interest, and one must talk on a subject about which one feels one knows, I have decided to present one or two aspects of industry rather than enlarge on the details of an isolated application of electrical engineering.

TREND OF INDUSTRIAL PROGRESS

The industry with which we are associated is, relatively speaking, young. Prof. Baily's admirable Address last session† gave a very clear picture of the steps of its progress; and when it is realized that from a secondary industry in 1910 it has grown with all its ramifications to the greatest undivided industry in the country in 1934, our importance and responsibilities in the structure of industrial Britain will be apparent. The prospect of further growth in almost every direction is still wide, and with this in view I make no apology for dealing in this Address with the responsibilities falling on us from the industrial angle. Some at least of what will be said may be looked upon as controversial, but at any rate an endeavour is made to reveal a scheme of things which is practical in its application industrially.

Industrialism to-day seems to be hastening towards a "jam," which must sooner or late create an international social crisis. Increasing skill in the technique of production is enabling industry more and more rapidly to fill each demand as it is created. One sees on all hands far-sighted salesmen talking of the saturation point of this and that commodity, and the necessity for the exploitation of new markets. Many of our engineering industries are now spending on selling, as much as, or more than they do on the actual wages of production. Still the ball rolls on; still the cry is "increase productivity," or "reduce costs," which is the same thing.

The sales effort increases to keep up with production; the enterprising young salesman learns Spanish with a view to developing the resources of South America—that vast, wealthy, sparsely populated Continent. Trade agreements with our Dominions are made, revised, and made again, but the salesman and the production engineer will never finish the race. Our little nation is no longer industrially isolated; we are racing with the nations of the world in this mad helter-skelter—faster, faster, faster, like the Red Queen and Alice in Lewis Carroll's fairy tale.

Look back to about 1910 and the advent of the Model "T" Ford motor-car. Here is the germ of production technique, and the elimination of the personal element in precision engineering. In 1914 the War came, and, in the deluge of demand, production was fertilized and propagated to scales undreamed of. High wages in 1918 gave a further fillip to the growth, and when the world depression struck us the productive capacity per head was at least double the 1910 level, and this in 20 short years. Since then we have attributed the demand for increased production to economics.

And all the time the senior executives on design, production, and sales, are increasingly bereft of leisure; the man at the machine tool and the assembly bench becomes less and less of a craftsman, and is degenerating into an automaton. The machine is beginning even to dominate the toolroom. We have concerns in this country now where the organization is such that the man at the bench at no time may or has to move more than 200 ft. from his work for any purpose whatsoever, from starting-time in the morning—including his luncheon break—to stopping-time at night. It will be agreed that the only excuse for such a form of work is the creation of more leisure. So far this has been achieved only to a very modified extent.

It is not the primary duty of the engineering industry to create employment. Our job is to make things of a quality and price which will render them useful and acceptable to the other folk; but when we have achieved this, it is our responsibility to see that our industry is one in which it is desirable to be engaged. Increased leisure and better working conditions become more essential as the labour becomes more arduous or monotonous; otherwise we lower the general standard of our artisan classes.

Now look ahead! Surely, supply can be illustrated as an inverted parabolic curve mounting at a rate which must ultimately reach an incline unscalable by the puny efforts of the salesman and economist. It is hoped that when these circumstances arise the international diplomatists and economists, with a sincerity of purpose untrammelled by the petty considerations which just now bulk so large, will get together and thrash out a better way of living.

The Engineer's Job

We as engineers have more to do with the creation of the present situation than anyone else. There is scarcely a task undertaken by man or beast which we have not mechanized, and as electrical engineers we have done more than our share of the work.

We call it progress, and the advance of science. We are right up to a point; the general amenities of the more civilized races have undoubtedly been improved by our effort. Now, however, the floodgates are open, and we flow on our stream of "progress" willy nilly, where we do not know. Our influence can only affect the course of our craft in the inevitable current.

The battle with Nature must continue; the conquest

* In the absence of Mr. MAVOR, owing to illness, the Address was read by Prof. F. G. Baily, the immediate Past-Chairman.

† *Journal I.E.E.*, 1935, vol. 76, p. 62.

of time and space must progress; we must go on with our part in the harnessing of the elements, and the redemption of the deserts. It's our *job*. If there is justification for the past, then our course is plain, and, as our work matures, the objective of making life easier and simpler for humanity will be approached near enough for philosophers and thinkers to take over from us and point the way.

Let me now pass to a few thoughts on how the engineer industrialist may tackle his job, so that his burdens may be eased and the zest of work may more fully be enjoyed.

Goodwill

A figure in pounds, shillings, and pence, termed "goodwill," often appears on the balance sheet of a public company. It is generally accepted as a tangible asset, and frequently used as a negotiating point when amalgamations are on foot. Should a company change hands and a new staff be set up, about 10 per cent of the goodwill so clearly valued may constitute opportunity. The old company's name has possibly attached a connection, but real goodwill only exists in a concern while its personnel is co-operating to do good. Its full value is not created until the customer, the company and its employees, and suppliers, are all benefiting from its activities; and when this is so, money cannot buy this asset.

Goodwill is created by mutual service, and success is its complement. By the degree of service rendered to humanity, the fruits of effort are valued and classified. History reveals the great on this basis: rulers, scientists, doctors, actors, even "movie stars," are assessed on their service or disservice alone when the time comes to look back on the result of their work.

Success really means service successfully carried out, and not, as is a common view, the collection of money; this may be, and often is, a sign of success. A man who merely collects for his own use more money than his neighbour may only be a parasite, or his claim to greatness may be in his degree of roguery. Many great scientists have died poor men; were they failures? In every walk of life we have examples of those who have succeeded brilliantly, with, in the end, little more tangible than their immortal names, gained by a goodwill generated from their service so willingly given to humanity.

The attitude of mind which puts industrial success in the category of financial gain alone is a dangerous one, emanating from a young and inexperienced country which is now in course of paying the price and readjusting her views on this matter. Her objective hitherto has not been to serve humanity but "to get rich quick," and "Deil take the hindmost." This is a violation of the rules, and the fruits are exceedingly bitter.

The tradition of our country throughout the industrial era, in spite of all the brutalities, anomalies, and inequalities which have come with industry, has been work well done and service rendered. We do not live up to this tradition always, but our stability—so splendidly demonstrated in these times—is due in the greatest degree to this attitude.

One other comment on this goodwill theme. This is an age of limited liability companies; many of the successful private concerns of the past have either been reconstructed or have disappeared altogether. Is this not generally due to the fact that the grand old fathers of industry carried so much on their own shoulders, and took for themselves such a large proportion of the reward for services rendered that the succeeding generations were often brought up on the fruits of the services, without knowledge of the cultivation of the tree? Theirs was the delusion that money was everything, and that goodwill was a financial asset. They became social nonentities whose one function was to send the old man's gains back by devious routes whence they came, while the old firm, all it stood for, and its employees, either took on another aspect or disappeared altogether. When the customer becomes only a secondary consideration to a firm, the status of that firm must move down the scale, and sooner or later a more enlightened competitor will supplant it.

Willy nilly, no matter what the outlook, all business is based on service. The user of the finished product pays for service, for service the employer pays his men, for service rendered we pay when raw material is bought, and so on right back. We pay the shopkeeper for bringing us his wares and presenting them attractively to our wives. We pay the milkman, not for the milk, but for bringing it to us; through him we pay the farmer for his service in rearing cattle and tilling the land. No item of commerce can be segregated from service, but we often fail to keep this fact in the forefront in our daily tasks; in a measure, service has begun to mean the *ex gratia* fussing around when a transaction is otherwise complete. If the product were perfect and entirely serviceable, this part of service would be unnecessary.

The successful company is the one which competes in the open market and takes the lead in service rendered; whether its quality be cheapness of its commodity, reliability, durability, or any other desiderata, they all come under the heading of service. It is then the duty of a company to make its commodities as well and as cheaply as is possible, and where necessary to ensure, by suitable personnel, that after the customer has bought and paid for the goods he is satisfied with the service they and the company give. In attaining this satisfaction, the balance between well-made and cheap must be struck correctly, for by this balance will the goods be judged. The company is wise which makes "cheap" the second consideration. To arrive at the value of the commodity, the service of the company must be assessed thus: (*a*) The capacity for production of the plant. (*b*) The cost of running the plant, apart from direct wages, materials, and use of machinery. (*c*) The cost of disposing of the product. (*d*) The cost of wages, material, and the use of machinery.

On this basis the factory is bound to dispose of a certain predetermined quantity of output before there is one penny piece for the shareholders, and if the output is not attained there is a loss, indicating either that the service offered is not wanted or that it is not good enough in some respect. This may be due to bad sales service, or an inferior product, or the wrong kind of product, but at all events it is due to defective service. Success in a business is therefore the capacity so to order its

services that it can procure a quota of work commensurate with its productive capacity. When it becomes necessary to raise the productive capacity, the return already gained by exceeding the economic minimum is most wisely applied in doing this; thus the reward of services rendered is applied to increasing the serviceability of the concern to its trading community.

This, however, is only the beginning of the matter; there is yet another and more important balance to strike. A firm or an industry will not eventually succeed if its prosperity is gained at the expense of its employees. In fact if it has not the resource to produce its service at a market value, which avoids imposing stringency on the lives of those engaged in it, it has indeed failed, and carries the most serious item on the debit side of the social account. It has been said "Let not the buyer rejoice and the seller mourn." In these days when commerce looms so large in our social structure these wise words have gained in force. Neither the buyer nor the seller may rejoice alone for very long nowadays. If the buyer rejoices all the time by reason of getting something for less than its value, the wheel will inevitably turn and crush him and his as time goes on, and the service he stole will die also. A fair price for a fair service can be ranked as one of the laws of nature, and we pay more dearly by its violation than by its keeping.

The social account is therefore not paid till our company works its service back to the other end of the scale. Each human unit in it is a unit of service to his neighbour; if he is not, then he is a disservice to the whole, and must be corrected or eliminated. A healthy business, with happy and contented employees, which pays fair prices to those from whom it buys and charges fair prices to those to whom it sells, is the greatest asset to industralism.

Unity of Effort

The long-recognized fact that "two heads are better than one" is not applied in industry to the extent it might be, because owing to human frailty the convening head must be, in some degree, slightly swollen. This can be observed in executives in a greater or less degree all up and down the scale, and it forms an impediment to the free thought, expression, and action, of the junior individual as a member of the team. A comment of the late T. E. Lawrence gives food for thought on these lines: "My peace must be mixed with effort. Damn! the conquest of the last element, the air, seems to me the only major task of our generation, and I have convinced myself that progress to-day is not made by a single genius, but by common effort. Genius raids, but common people occupy and possess." These are the words of a young man, a genius who had raided, and who latterly got down among the common people to work out his principle.

Each of us who is in an executive position must be in a measure one of Lawrence's raiders, but the occupying and possessing can only be done by common effort, and this may only be achieved by sympathetic understanding of all those with whom we work, and deal. If, for example, the junior staff and the day wage-earners in our industry cannot be shown a horizon farther than the end of the week, their pay envelope, and the small item in the organization which is their individual charge, their contribution to the common effort will have no more influence than the turning of an idle pinion—the passing-on. The underling cannot be given a complete picture of his relative position and importance in the organization, but he can be given a live interest in what he is doing and why. He can be interested in how the company, *his* company, is progressing, and what the prospects are for him, even if only as to continuity of employment.

This has been called the "personal touch," and it is argued that it is well-nigh impossible to get in the large industrial concerns of to-day. Granted all the difficulties which stand in the way, it is a consummation which must be gained if the best is to be got out of industry and the difficulties and social problems of to-day are to be faced and overcome.

I am satisfied that it is not only possible, but essential, that the spirit of mutual understanding and co-operation should be fostered in a way which will permeate downwards through all ranks in our industry: till in years to come it will be realized by all, down to the least operative in the factory, that his relative status in the firm is one of importance. He will then do his work well, not because of the dire personal results of his failure to do so, but because he feels that indeed his firm's work is judged on the basis of his work, as it is on the basis of the managing director's.

In short, we, as industrialists and commercial men, should face facts with courage, putting on one side bluff and other knavish tricks which we use to hide our human frailties. Mutual understanding may not be gained except by making the other fellow understand you. Science and the pursuit of science is based on facing facts in relation to things inanimate. We engineers all know how to face those facts, because we must. It should not be such a long step for us to face the facts of humanity which daily we dodge, making life in our industry more complicated and difficult, aye, and unhappy.

The basic error of endeavouring to teach the handling of personnel under titles such as "industrial psychology" is to-day common. The understanding of one's fellow men cannot be *taught*, but must be *learned*, just as one, by rubbing shoulders with one's fellow men, learns by trial and error how to conduct oneself in an acceptable manner. To take the pains to be fully understood by and to understand one's inferiors, is to gain an appreciable asset in commerce and industry; just as the greatest asset in selling is to understand the outlook of the user and to present the case accordingly. This is all too vital a matter to be taught as a science; books may point the way, but they are liable to mechanize the outlook and warp the individual attitude. The lesson is always with us in the individuals we meet daily, and is waiting to be learned.

These remarks will appear only to prick the surface of the subject—this is intentionally so, for the reasons just stated. An effort to teach a man how to conduct himself to his fellow men is just "check." My effort has been to inspire further study.

IRISH CENTRE: CHAIRMAN'S ADDRESS

By WARREN STOREY, Member.

"TWENTY-FIVE YEARS OF ELECTRICAL DEVELOPMENT ON THE IRISH FREE STATE RAILWAYS"

(ABSTRACT *of Address delivered at* DUBLIN, 31*st October*, 1935.)

I propose to confine the scope of this Address to what is now known as the Great Southern Railways system, and to deal with my subject under three heads, namely: electrical equipment in railway workshops; train and bus lighting by electricity; and electric traction.

ELECTRICAL EQUIPMENT IN RAILWAY WORKSHOPS

Generating Equipment at Inchicore Works, 1900–1935

Electric power was first introduced into the Inchicore works about the year 1900, when three 10-ton electric gantry cranes were installed in the boiler shops, power being supplied from a 220-volt d.c. generator driven off a shop line shaft. During the next few years several smaller electrically-driven machines were added, and in 1907 a cylinder planing machine, operated by a 30-h.p. motor, was installed in the machine shop. It was then found that a larger generating plant would be necessary to cope with the increasing electrical load, and the nucleus of a power station was formed, the first generator being a 60-kW Sisson–Crompton steam set, steam being supplied by an old locomotive boiler burning sawmill refuse.

About the year 1911 the railway company decided to build new carriage and wagon shops at Inchicore, which were to be all-electric, with a loading of approximately 300 kW. The major problem then was to decide what voltage and current were to be standardized in the works, having in mind that already a 60-kW 220-volt d.c. generating plant was operating. As this type of supply appeared to be general for railway workshops at that time, it was decided to continue on the same lines. Accordingly, a new power station was built, equipped with two 210-kW Sulzer–B.T.H. full Diesel sets. These sets supplied the increasing load in the works until about the year 1914, when the plant became overloaded.

Up to this period the electrification of the locomotive shops, sawmill, etc., had not been considered, the shafting in these shops being operated by several vertical steam engines, mounted on the walls and with crankshafts direct-coupled to the main shafting. Power was transmitted between the various shops through belts, ropes, vertical shafts, and bevelled gears. The wall-mounted steam engines were now removed gradually, and the line shafts driven by individual motors at a speed of approximately 180 r.p.m. Comparatively low-speed motors had to be installed, as it was difficult to get large-diameter pulleys on to the line shafts owing to their proximity to the walls.

This gradual electrification continued until 1916, when it was decided to increase the capacity of the power station by the addition of two 400-kW Belliss and Morcom–B.T.H. steam sets, bringing the total generating capacity up to 1 300 kW. Steam was obtained for these engines from a battery of Babcock and Wilcox boilers, equipped with specially adapted fire-boxes to take sawmill waste to the extent of 10-ft. outside slabs, as well as sawdust.

When further generating capacity became necessary it was decided to take a bulk supply of power from the Pigeon House power station, and a substation equipped with the necessary transforming plant was built beside the railway company's power station.

Approximately two-thirds of the load of the works was equipped with a.c. motors, the balance (which, of course, included all the variable-speed motors) taking a supply from one of the steam sets. This arrangement enabled the company to find use, to some extent, for their sawmill waste.

With the amalgamation of the majority of the Irish Free State Railways in 1925 came the necessity for a complete reorganization of the machines in the Inchicore workshops. The locomotive, carriage, and wagon shops in Dublin belonging to the late Midland Great Western and Dublin and South-Eastern Railways, and several smaller works throughout the country, were closed and the entire plants transferred to Inchicore. These transfers made it necessary to remodel the Inchicore cable network considerably, and to increase the electrical load. The extensions were undoubtedly facilitated by the fact that a substantial amount of the electrical machinery taken over was suitable for the existing 346-volt 3-phase or 220-volt d.c. supplies.

The elimination of direct-current plant, as far as practicable, was then proceeded with. The installed d.c. load was reduced to within the region of 100 kW, to supply which two Bruce-Peebles split-pole convertors were provided, thereby releasing one of the 400-kW steam engines for driving an alternator as a standby to the existing Electricity Supply Board's supply.

This position obtained up to 1934, when it was decided to build new locomotive erecting shops, and as these shops were also to be "all electric" it was again necessary to remodel the electrical supply. The Electricity Supply Board accordingly increased the capacity of their substation by 50 per cent. The equipping of these new shops involved yet another rearrangement of machines, and the cable network was therefore again upset. In a works such as Inchicore a permanent cable network is practically impossible owing to the almost incessant

shifting of machinery from one shop to another, the introduction of up-to-date machines, and the latest practice of bringing the machine to the job rather than the job to the machine.

The growth of the electrical plant at Inchicore may be summed up by the statement that in a period of 25 years it has advanced from a 20-kW belt-driven generator to the present 2 000-kW supply.

Plant and Machinery at Inchicore Works

Line Shafts.

When it was decided to electrify the steam-driven line shafts it was found inadvisable to separate the machines and that it was more economic to drive the line shafts, or groups of machines, by single motors. Some of these are chain-driven, some belt-driven, and in a few cases gear drives are in operation. Formerly the standard practice of manufacturers of machine tools was to provide for the driving of such tools from line shafts, so that the millwright engineer had really no choice but to perpetuate the grouping system of drive. The modern tendency, due to the introduction of electric power, is to aim at individual drives on practically all workshop machines, and in a great many instances the line shafts have become lighter owing to certain machines having been moved or scrapped and replaced by individual-drive or self-contained machines. These remarks are particularly applicable to the sawmill, where originally a 300-h.p. motor had been installed to drive the main line shaft. Subsequently two self-contained saws were introduced absorbing 84 h.p., so that the motor driving the main line shaft is now much too large for its job. We hope, in the near future, to install individual drives for the remainder of the machines, or at least to replace the main shaft by one or two smaller line shafts, thereby reducing frictional losses enormously and avoiding the complications which must always arise from belting and shafting in a sawmill pit.

Gantry Cranes, Transporters, and Traversers.

There are 31 gantry cranes, transporters, and traversers in the works, varying in capacity from 50 tons to 2 tons, 4 of 40-ton capacity having been erected in the new shops. The development of gantry cranes has, in the past, been carried out with direct current, which has proved most satisfactory owing to the flexibility of speed control. In this connection special mention may be made of our foundry gantry cranes where, during casting operations while pouring from a ladle often containing over 10 tons of molten metal, very slow and accurate movement is essential.

The advance in design of a.c. motors has, however, greatly facilitated the universal use of alternating current in a works such as Inchicore; the gantry cranes recently installed in the new shops are equipped with variable-speed a.c. commutator motors. This type of motor is also employed to drive the surface traversers and transporters.

I should like to refer here to a coal- and ash-handling plant which was installed at Inchicore some few years ago. This plant includes an elevated bin or hopper having a capacity of 450 tons. Wagons of coal are shunted on to a table beside the bin, which then elevates them to a height of 56 ft. and tips the wagon of coal into the bin. Locomotives passing under the bin receive their complement of coal, which is duly weighed and recorded. The entire plant is operated by a.c. motors and controlled from the ground. Before a locomotive is coaled, ashes are dropped from it into a pit lined with a steel bucket, which, in turn, is elevated and disposes of this ash into empty wagons. The two operations described occupy a very short period, and considerable economy in labour has resulted from the installation of the plant.

Planing Machines.

Planing machinery in a railway works is of very great interest, since the machines are difficult to drive and their consumption of power is considerable. A number of the planing machines at Inchicore are equipped with quick-return tables capable of handling loads up to 20 tons. The method is to operate the table on the cutting motion at low speed, and on the return movement at high speed. One of these machines in particular is worthy of special mention: this is a planer designed and manufactured by the Stirk Hiloplane Co. The table is operated by a 50-h.p. reversible d.c. motor, other motions—including longitudinal, vertical, and cross planing, milling, slotting, and boring—being operated by two 10-h.p. motors. To obviate what is known as "backlash" on the table, or what might otherwise be described as the "dead centre," a motor-generator is employed in conjunction with the main motor. This, in turn, is operated by a series of contactor switches; and the whole machine, including tool setting and cutting, is under push-button control by the operator.

Electric Welding.

At present there are upwards of six electric welding plants in daily use in the shops at Inchicore. These plants comprise both a.c. and d.c. systems, each having its particular characteristics and uses. Prior to the development of the welding process, broken or cracked parts of coaches, locomotives, etc., had usually to be scrapped, involving considerable delay and expense. All the plants are mounted on wheels, and, as the shops are all equipped with suitable power plugs, the usual practice is to bring the welder to such jobs as locomotive smoke-boxes, frames, side-tanks, cabs, and bunkers; wagon bodies; coach underframes, etc. When the welding plants are not in use on such work they are kept in special places where smaller operations are attended to, such as ash-pans; spokes and rims of wheels; boiler domes, rolled and welded; motion parts; brake gear; etc. Spot-welding machines are employed in the sheet-metal shops for a variety of less important work. This class of welder is also used to advantage in our road-vehicle shops for innumerable jobs.

The widened scope of electric welding and its practicability make it safe to predict that there will be considerable advance in this direction at the Inchicore works during the years to come. For certain classes of cutting work, the oxy-coal-gas method is used to advantage, and a new universal cutting machine of this type has been installed. This machine is capable of cutting steel plates clamped together to a thickness of

15 in. (thicknesses up to 11 in. have actually been cut). The cut is controlled magnetically.

Compressed-Air Plant.

There are three large-type compressors at Inchicore, driven by 100-h.p., 120-h.p., and 150-h.p. motors, respectively, the controllers of which are operated by air pressure. These compressors are in daily use, as it has been found that portable machines such as riveters, hammers, cutters, drillers, etc., are more suitably operated by compressed air than by electricity. Perhaps the greatest disadvantage of electric portable machines, is weight; this particularly refers to drilling machines, which have to be partly supported by the operator whilst in use. Consequently the use of compressed-air portable machines is general throughout the works, although the power cost for the class of work dealt with is considerably higher than that of electric portable machines.

Lathes.

A large percentage of the total current used is employed for driving lathes of various types. There are upwards of 50 of these machines in the works, including wheel, crank, and turret lathes; semi-automatic lathes; screw-cutting lathes; etc. Wheel lathes play a very important part in a railway works, seeing that all wheels have to come in periodically for turning. Rails get worn out and require replacement, and tyres working on these rails become worn irregularly and strain-hardened on the surface, and must, in consequence, be turned to gauge. The most modern high-speed wheel lathes obtainable, of British and American manufacture, have been installed at Inchicore The engine-wheel lathes are capable of handling wheels up to $6\frac{1}{2}$ ft. diameter and making cuts to the extent of $\frac{1}{2}$ in. and over on tyres. A feature of the Craven wheel lathe worthy of special mention is the dynamic braking arrangement.

Chromium Plating.

The advent of chromium plating opens yet a further outlet for electricity as applied to railways and road transport. Practically all bus fittings, both inside and out, are now chromium-plated, and the same finish is being increasingly used for the inside fittings of railway coaches. The process is one of electrodeposition, and calls for large current outputs at low voltage. For decorative chromium the current required is approximately 70–80 amps. per sq. ft., and is usually supplied by direct-coupled motor-generators, standard machines being supplied up to 8 volts, 5 000 amps. Motor-generators are also used for electrical cleaning, nickel plating, etc., which form part of the process of chromium plating. A further development is hard chromium plating for parts subject to hard wear. This deposit is so hard that a file will not damage it; its possibilities are very great.

Shop Lighting.

Electricity and high-pressure gas are employed for lighting the Inchicore works. The latter method was installed when the company had its own coal-gas works at Inchicore. Gas lighting was carried on after the railway company had begun to take a bulk supply of coal gas from the Alliance and Dublin Consumers' Gas Co., and, as it has been found difficult to dislodge gas on a cost basis, about one-third of the works is still gas-lighted. The remainder of the shops are illuminated by high-candle-power gasfilled electric lamps with suitable reflectors, which are suspended over the gantry cranes. All these cranes carry cluster reflector electric fittings placed underneath, to compensate for any light obstructed by crane girders. Some lighting has also been carried out with high-pressure mercury electric discharge lamps, and the extension of the use of this type of lamp is being considered. In shops where electric lighting is in use, standby gas lights have been installed, and standby electric lights are provided in gas-lit shops.

Energy Consumption

It is realized that electrical energy is one of the chief agents of production, and every care is exercised in the checking and control of consumption. Meters are read at certain fixed periods, and the energy consumed is carefully charted, priced, and allocated to its proper charge. Any variation is immediately detected and investigated. The system in operation also enables the management to make periodical comparisons of rise and fall in consumption.

TRAIN AND BUS LIGHTING BY ELECTRICITY

Road Transport

Another branch of the activities of the railway electrical engineer has been brought about by the transfer of the various road transport services to the Great Southern Railways. To meet the pressing demands for immediate up-to-date reliable road transport, over 200 of the latest-type passenger buses and 150 motor lorries to cater for beet traffic, have been built and equipped in the Inchicore shops. The electrical equipment of these vehicles required expert workmanship and supervision during the installation period, and the future maintenance of such gear necessitates the efficient organizing of a system which is now being developed.

Train Lighting

In dealing with the electric lighting of railway carriages I propose to concentrate on the self-contained equipment normally associated with steam-drawn railway carriages which has been adopted by the Great Southern Railways, as distinct from the equipments for use in electric traction where the supply of power for lighting and other services is drawn from an external conducting medium.

Early Single-Battery Systems.

The first successful attempt at the electric lighting of railway carriages was made by the medium of the carriage axle and a belt-driven dynamo, but owing to the widely varying speeds encountered it was found necessary to provide some means whereby the output of the machine could be controlled over the wide range of speeds at all time associated with railways. The earliest efforts were made by screwing the dynamo to the floor of the guard's van; this method was soon replaced by the suspension of the dynamo from the underframe, the suspension being arranged in such a

manner that at a predetermined output the belt would slip and the dynamo output could not then be increased beyond the stipulated figure. About 50 per cent of the carriages lit by electricity to this day have their dynamos regulated in this manner.

Another problem arose from the fact that all train-lighting dynamos must give the same terminal polarity in either direction of rotation. This requirement was usually catered for by the provision of some form of change-over device, fitted to the dynamo and operated by the reverse movement of the armature and the resistance to movement offered by the brushes on the commutator.

The next problem was that of lamp voltage regulation. Since a battery on charge may be expected to give a rising voltage which would rapidly reach a value that would either burn out the lamps or shorten their life, it was necessary to provide a means whereby the lamp voltage could be corrected as the battery voltage rose with charging. In a rough-and-ready manner it was found that a varying amount of resistance might be inserted in the lamp circuit, always providing that the lamp load or discharge rate was correctly proportioned to the capacity of the battery. The lamp resistance was inserted in the main lighting circuit by the action of three simple contacts over the cut-in switch, the final operation of which was controlled by the magnitude of the current charges supplied to the battery.

Double-Battery System.

The next important development was to split the battery up into two parts, each of the full voltage but having half the capacity of the single-battery arrangement, and by this means it was found possible to charge one battery whilst the other floated across the lamps. It was thus possible to separate the high voltage due to charging, from the correct voltage required by the lamps. This necessitated some form of change-over switch in order that the batteries might be charged in regular rotation, and to improve the efficiency of the arrangement the two batteries were coupled together by a resistance in which the voltage-drop was equal to the maximum charging voltage of one battery minus the standing voltage of the other. Thus the dynamo would not only adequately charge one battery but would also generate sufficient current for the lamps, leaving the floating battery in a static condition and thus providing a stable condition of lamp voltage. This is precisely how double-battery equipments are arranged to-day.

If the lamps are individually switched and the dynamo current output is constant, there must be a tendency for the floating battery to receive a charge in proportion to the number of lamps that are switched off, and as a result its voltage will tend to rise. This is not a serious matter, however, provided the individual switching is limited to 30 per cent of the lamp load for which the resistance between the two batteries has been designed.

Modern Single-Battery System.

In the case of modern single-battery equipments the problem is rather more complex, and involves the use of a regulator sufficiently accurately set and designed to insert resistance in the lamp circuit as the battery voltage rises on charge. The design of such a piece of apparatus is by no means simple, taking into consideration the widely varying conditions of lamp load, battery voltage, and train speed, that may be encountered on any railway system.

The lamp-voltage regulation can be materially assisted by limiting the charge supplied to the battery, or preventing the battery voltage from rising too high, but if this is done there may be serious difficulty in keeping the battery in a healthy condition on slow-running or suburban services. The modern single-battery equipment is generally arranged so that the current charge rate to the battery is only materially limited when the lights are switched on.

The problem has now been discussed sufficiently to indicate what essential pieces of apparatus are required if a high standard of performance is to be obtained.

Comparison of Single- and Double-Battery Systems.

The double-battery equipment includes a dynamo, a cut-in switch, two batteries of cells, a battery-charge regulator resistance, and a battery change-over switch, besides the necessary fittings, cable, etc.; whereas the single-battery equipment combines the use of a dynamo with its attendant shunt regulator, a cut-in switch, an automatically-regulated lamp resistance, a battery-charge controller or limiter, and auxiliaries similar to those for the double-battery arrangement.

Dealing with the single-battery system first, there is a greater ampere-hour efficiency owing to the larger cells and their capability of receiving a greater number of ampere-hours in a given period of time. Unfortunately, the fullest advantage cannot always be taken of this characteristic unless some form of lamp-voltage regulator is included in the equipment, as without this the voltage of the dynamo and battery must be limited to an extent likely to prevent the battery from becoming properly charged under slow-running or suburban traffic conditions. An important point in favour of this system is that the adjustments necessary to provide for individual switching of the lamps can be effected conveniently by the lamp-voltage regulator, a point which some train-lighting engineers consider indispensable for the best class of vehicle equipped with this system.

On the other hand, a double-battery system of train lighting offers the advantage over the single-battery arrangement of giving satisfactory lamp-voltage regulation with the minimum amount of apparatus, provided the lamp load does not vary beyond the capacity of the resistance between the two batteries, which must be so proportioned that it will absorb the difference of potential between lamps and charging battery under all conditions of speed and dynamo output. The reason why the floating battery must be prevented from receiving a charge is the fact that the voltage of every known form of secondary cell rises with its charging to an extent that would probably burn out the lamps if allowed to persist. Consequently one might argue that even with the double-battery equipment some form of lamp-voltage regulator must be adopted if individual switching is desired. Such a regulator is unnecessary, however, if the voltage of the charging battery is limited by an over-charging device.

Slipping-Belt Dynamo.

Mechanical engineers have always had a horror of the slipping belt; nevertheless, I personally have witnessed tests showing that a belt life of 50 000 miles is not only possible but a fair average for main-line working, and a somewhat shorter life is obtainable for suburban services. In the early days of train lighting it was discovered (more or less by accident) that the belt drive is always attended by a certain amount of slip, depending largely on the tension in the belt. By suspending the dynamo from a single point and adjusting the belt tension to give the correct dynamo output only, a perfectly reliable control of the dynamo current output can be obtained, and the wear on the belt will not be excessive, providing the slip at the full-out speed of the dynamo and that at the maximum speed of the train are kept within a ratio of not more than 3 : 1, i.e. (say) full output at 25 m.p.h. with a maximum train speed of 60 m.p.h.

The slipping torque of a belt after proper adjustment depends upon the product (Current output of dynamo) × (Number of armature conductors) × (Strength of field). This value of torque is definitely fixed when the tension screw of the dynamo suspension is adjusted, and it is only at this value that the belt will slip; for instance, if the strength of the field is increased with the rising voltage of battery and dynamo (as it must be on a plain shunt-wound dynamo), there will be a definite and progressive falling-off in the dynamo current output, thus automatically providing the drooping characteristic which is most desirable for the ultimate recharging of the battery. Conversely, if the field of a shunt-wound slipping-belt dynamo is weakened by the insertion of a limited amount of resistance in series with the field windings, the armature will be burnt out unless the belt is readjusted to suit the altered conditions.

ELECTRIC TRACTION

Battery System

The application of electric traction has been under consideration on several occasions since the introduction of a national electricity scheme in the Irish Free State, but owing to the many sparsely populated areas the high cost of complete electrification could not be sufficiently justified. In one suburban area, however, namely Amiens Street (Dublin) to Bray, conditions appear to favour the faster and more frequent service that an electrified system offers. Moreover, the invention and development, by Dr. Drumm, of an alkaline type of traction cell combining the good qualities of the lead-acid and alkaline types has revealed certain possibilities for the partial electrification of the system, and particularly of the area referred to.

The Drumm battery is composed of a metal case containing positive and negative elements in an alkaline electrolyte, and its construction is similar to that of the Edison cell. The main advantage of the battery is its high charge and discharge current for its size and ampere-hour capacity. Two 2-coach units operated from Drumm batteries have been working on the Amiens Street–Bray section for over 2 years, and have completed more than 100 000 train-miles. Regenerative braking is employed, and is assisted to a great extent by the ability of the Drumm battery to sustain rapid rates of energy input a considerable number of times per day. The weight of the 2-coach unit complete with batteries and electrical equipment is 70 tons with a seating capacity of 140 passengers, the gross weight being 85 tons. The trains are equipped for multiple-unit operation. The coachwork and mechanical parts were designed and constructed at the railway company's Inchicore works. The units are of the 2-coach articulated type, the centre or power bogie being of a special design with a high axle load utilized for adhesion purposes.

The cells (272 per train unit, weight 15 tons) are housed in four containing boxes suspended from the underframe, one on either side of each coach. Current is supplied from the fully-charged battery at 500 volts, and is controlled by electro-pneumatically operated switches and contactors in the usual series-parallel manner. This apparatus is housed in the main equipment compartment over the motor bogie, which also contains a motor-driven air-compressor for operating the switches, pantograph, etc. Electric drive is applied to the centre bogie by a 200-h.p. motor on each axle, and the control equipments (both main and auxiliary) are housed in compartments directly above the motors, thus ensuring that all high-tension current is isolated as far as practicable.

The arrangement of controls in the driver's compartment is as simple as possible. The driver is seated on the left-hand side, and the master controller and brake valve are so placed that he can conveniently operate them whilst seated. The hand brake is to his left, and the switchgear for headlights, etc., to his right. The vacuum horn is controlled by a chain suspended directly in front of him. In the passenger compartments the lights are carried on the ceilings in vitreous-enamelled fittings, and electric heaters are fitted under the seats.

Two charging stations have been erected, one at Amiens Street and the other at Bray. These stations are equipped with transformers, mercury-arc rectifiers, and automatic control apparatus. The two stations are identical, with the exception that Amiens Street is designed for an incoming supply of 5 000 volts, 3-phase, 50 cycles per sec., while the station at Bray is designed for 10 000 volts, 3-phase, 50 cycles per sec. Each equipment is capable of supplying continuously 900 amps. at 630 volts direct current, 1 000 amps. during 30 minutes, and 1 350 amps. during 2 minutes. It is possible to charge the train batteries on each occasion that the train stops at either of the charging stations, the rectifier equipment being automatically switched on when the pantograph on the train is raised and shut down when it is lowered. A remote-control box is situated on the station platform, so that the rate of charge can be varied if required without the necessity for going to the substation. An alarm bell fitted to this control box will bring any irregularities in the substation to the notice of the station staff. The current at both substations is taken from the Shannon power scheme.

Suburban Electrification

With regard to the proposal for electrification of the suburban Dublin–Bray–Greystones line, the following

alternatives present themselves for consideration: (1) Complete operation by Drumm-battery trains. (2) Complete electrification on the continuous-contact system. (3) Electrification by Drumm-battery trains, with a certain number of steam trains retained for service during the rush hours. (4) Diesel-locomotive traction.

Undoubtedly with continuous-contact electric trains it should be possible to work a train service at least 100 per cent greater than at present. On the other hand, before a scheme of electrification is embarked upon the capability of the method adopted to cater for the present and future traffic requirements must be demonstrated, and that the total additional revenue earned would be sufficient to give a satisfactory return on the large amount of capital expenditure involved; also that the advantage of being able to run additional trains would not be counterbalanced by a reduction in passenger receipts per train. The electrification of a system such as the Great Southern Railways must be carried out gradually, the experience gained on the particular section under consideration being used as a guide in regard to extensions to other sections of the line.

STAFF

Before I conclude I should like to say that for the carrying-on of the electrification work described in this address one of the main essentials is a highly trained and thoroughly qualified staff, and the company have always secured and maintained this important requirement. Attention is given to the selection of suitable men, and every care is paid to the training of apprentices.

CONCLUSION

I have endeavoured to picture in this address the progressive development of the use of electricity on the principal Irish railway. In spite of depleted traffic and the consequent scarcity of available money, substantial progress has been made, and electric current from the national supply has been utilized to a very great extent in our workshops and depots. If conditions continue to improve, we shall take advantage of favourable legislation and increased traffic to go forward and keep in line with the most modern electrical practice.

EAST MIDLAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By F. H. POOLES, Associate Member.

"ELECTRICAL DEVELOPMENT"

(*Address delivered at* LOUGHBOROUGH, *1st October*, 1935.)

INTRODUCTION

It is not my intention to seek to cover the whole field of electrical development in principle, or even to treat in detail any particular aspect of the subject. What I have set out to do, however, is to place before you as clearly as I can the various thoughts which occur to me in relation to matters which are likely to affect the development of electricity supply in this country during the coming years, and also as regards the possible results accruing from such development.

In spite of the phenomenal growth of the electricity supply industry, particularly during the post-War period, it is contended on all sides that the saturation point is not yet in view. We are continually faced by a constantly-receding mirage on the horizon of progress, which, whilst allowing us to form some estimate of future developments, reminds us that we must be continually adjusting our perspective to the change brought about by inventions and the application of electricity to new purposes. The development of domestic electrification is accelerating at a rapid rate; electrical heating is making considerable headway; the field of air-warming and air-conditioning is practically untouched; whilst television will become commonplace in the near future; and we are equally sure that much more will follow.

GROWTH OF CONSUMPTION

It is said that comparisons are odious. This is particularly true when we compare the 2 000 units used per head of the population in some cities of the United States with the corresponding data from our own undertakings. In the year 1932–33, for example, only 54 of the 614 undertakings in this country sold more than 300 units per head of the population, whilst one-half of the undertakings sold less than 100 units per head. Furthermore, when we observe that 73 per cent of the units sold are used for power and traction purposes, the average number of units used per head for domestic purposes falls to a very minute figure.

It is apparent that a considerable amount of driving force is needed in the electrical development of this country, for even if the output continues to increase at the rate of 7 per cent per annum another quarter of a century will elapse before we approach an average output of 2 000 units per head.

In making this comparison it should be noted that, although the present output of certain American cities may be taken as a measure of our progress, it is hardly fair to compare the data too closely, as the conditions in the two countries have a considerable effect upon the actual development.

GENERATION

Let us turn our attention for a few minutes to the field of generation, where the co-ordinated operation of selected stations under the control of the Central Electricity Board is introducing progressive rationalization. In the course of years, as the scheme develops and the grid tariff becomes less than the cost which stations "selected" under the 1926 Act would have incurred if the Act had not been passed, the pecuniary advantage accruing to undertakings which continue the ownership of generating stations will gradually disappear, and consequently it is probable that further developments in the ownership of such stations may be anticipated. Further co-ordination of control in this direction is indicated when we consider that about £7 millions are spent annually on fuel supplies for generating stations of authorized undertakings, and when we contemplate the economy which would result from the centralized purchasing of such supplies by a central authority.

For the purpose of this Address, let us assume an annual increase of 7 per cent in energy generated, and review the effect that this output will have on allied industries in the course of the next quarter of a century. The coal required to generate the amount of electricity represented by a consumption of 2 000 units per head, unless radical changes in prime movers take place, will absorb one-fifth of the present output from our mines. Over this period the gradual elimination of domestic fires, and the lessened consumption of industrial fuels through the electrical development, will adversely affect the sales of profit-bearing fuels; and it is probable that, in order to compensate for this loss of revenue from coal sales, hydrogenation or low-temperature carbonization may be developed on a large commercial scale. From the abovementioned quantity of fuel there are obtainable, by the low-temperature carbonization process even, about 135 million gallons of oil and 300 million gallons of tar, and it is improbable that we shall be allowed to consume these valuable by-products in our boilers. Thus it is reasonable to predict that distillation plants will in future be operated in conjunction with power stations, the major portion of our fuel being semi-coke supplemented by gas and heavy oil.

Should we experience this increase in output our ideas on super-stations may need modification. The position may be reached where the advantage of mass production will be cancelled out by distribution losses and other disadvantages. The development of stations nearer the centre of the load, operating in conjunction with distillation plants, with the probable use of oil or gas engines to cater for peak loads, may be seen. No radical change

in prime movers appears in view at present. We shall no doubt see developments in forced-circulation boilers in the near future, but thermal efficiencies over 40 per cent seem remote. Perhaps, on the other hand, some commercial use will be developed to avoid the serious waste of heat discharged in the circulating water.

DISTRIBUTION

It is opportune that a Committee of Action has been formed to investigate the problem of distribution, and it is hoped that this venture may at least result in the recasting of our areas of supply, whereby the country will be apportioned into the most economical distribution areas. Should some such development result, guided by a Central Board pursuing a uniform policy of earnest development, it is essential that the means for experiment should be preserved for local and regional bodies. In addition, the formation of a standard costing system for distribution, and the dissemination, comparison, and discussion, of its results, would assist greatly in the avoidance of uneconomic expenditure. It should be noted that the present absence of a standard system of costing militates greatly against the true comparison of costs.

In the past any comparison of the results of an undertaking has generally been centred on an index of thermal efficiency of the generating station, although the cost of distribution has generally been greater than that of generation. It is anticipated that results will in future be estimated on the basis of distribution efficiency, which will probably be measured on some such criterion as the number of units sold per £ of distribution capital expended, with consideration given to the type of consumer supplied. It is apparent that considerable research is needed in order to formulate a desirable unit of comparison. The advent of the Central Electricity Board, and the payment to it at tariff rates for all units purchased, may result in more attention being focused on units expended on distribution. When we consider that authorized undertakings will be paying about £2½ millions a year to the Central Board for units to be expended in distribution, representing nearly 13 per cent on the average of units sold, it is apparent that the subject will be early in the limelight. Of course, it is costing the undertakings that sum at present, but the cost is not so apparent as will be a direct payment on the basis of units purchased from the Board.

Reverting, for a moment, to the probable reorganization of distribution, perhaps the most urgent need of development is the formation of regional technical pools, whereby local undertakings in the area may draw on the services of highly specialized technical salesmen in the development of specialized loads.

With the increased loads on the distributing system, the range of substations will become more limited, and higher distribution voltages will be necessary. Automatic feeder regulation will be essential in outlying districts. We shall see, too, developments in supervisory control by means of carrier currents, superimposed on the normal current in the mains, for the control of special loads, metering, switching, etc. The standardization not only of frequency and voltages but of substation layout, switchgear, meters, and cables, with a considerable reduction of the varieties at present in use, may be looked for. Also, considerable simplification and standardization is undoubtedly called for in the case of domestic electrical apparatus if we are to develop our domestic load to its fullest extent.

INDUSTRIAL APPLICATIONS

I now propose to review some of the sources from which our main development will accrue.

Industrial electric heating is fast gaining ground. Steam-raising by electrical methods is already well established in process work, and for curing tobacco, sterilizing work in dairies and on farms, in bacon curing, and hosiery manufacture; whilst chemical factories, laundries, textile factories, restaurants, and swimming baths, are gradually being equipped with electrode boilers.

It is interesting to note that electric annealing ovens and electric furnaces for special steels are gradually, but surely, we hope, replacing the existing methods. Although such development has taken place in connection with the industrial heating load, the present load is quite a small proportion of our motor load, and, if figures could be obtained, it is doubtful whether it would exceed 20 per cent. Comparing these data with the latest statistics from the United States, where the industrial heating load equals the motor load, one realizes that we have a large potential load awaiting development.

From the point of view of close regulation of temperature and ease of control, experience has already proved that electrical methods are without equal, and even where the comparative estimated cost of heating is against electricity the uniform results obtained have shown large financial savings. Therefore, given more economic tariffs, a large increase in this load should be realized.

One of the necessities to our national comfort which is long overdue is the electrical warming and conditioning of air, particularly in public buildings. We should develop a useful load in this direction in the future, and the pioneers who are at present doing yeomen service for the industry should reap a fitting reward. At the present we lag far behind foreign practice in this respect.

ELECTRIC TRACTION

Railway electrification should prove a good load-builder in the near future. In spite of the views of the steam "die-hards," one realizes that this mode of traction is fast gaining popularity. First of all, the extension of suburban electrification will be seen, followed, at a later date, when economic and financial conditions allow, by main-line electrification.

The electric battery-driven vehicle is fast establishing itself as the cheapest and most satisfactory means for local deliveries, where numerous calls have to be made in limited areas. Fleets of these vehicles can be seen in our streets, and they have now become serious rivals to other means of transport.

DOMESTIC LOAD

In the field of domestic electrification we have perhaps the greatest scope for development. For the all-electric home represents the highest standard yet attained in

comfort, health, convenience, and economy of labour. The development of the all-electric home will undoubtedly transform the lives of the people, and the effect will be particularly marked in regard to the housewife, who is already receiving beneficial results from the help afforded by electrical methods of carrying out household duties.

The existing wide divergency of units sold for domestic purposes is apparently not due to industrial or geographical causes, but rather to variation in selling force. As I have stated before, very few undertakings show annual sales for domestic purposes in excess of 300 units per head of population; on the other hand, many do not exceed 50 units per head. It is apparent that something vital is missing in the case of the undertakings of low domestic output, and also that considerable load is there, awaiting development. When we reflect that, in the borough of St. Marylebone, the number of units used per annum per head of the population for all purposes exceeds 1 000, and only 5 per cent of the load is power, we can gauge in some measure the absolute inertia of many undertakings with regard to domestic electrical development.

Undertakings should take all necessary steps to acquire benefit from the various schemes of slum clearance and rehousing in process and contemplated, by introducing as far as possible the use of electricity in these homes. In this connection, the use of fixed-charge collection, whereby a 2-part tariff may be utilized, should have beneficial and increasing results.

Whilst one realizes that the 2-part tariff will be with us for a considerable time, the extended use of electricity should result in a better diversity and load factor, and, with an improvement in this direction, the benefit of a periodical charge, with unlimited supply for domestic purposes, will be an ideal capable of attainment. As a result of this, considerable savings should be possible in distribution cost. In the absence of meters on consumers' premises, the periodical meter-reading and expensive account-keeping necessary at present would be obviated; as also would the loss of the units required to operate meters, which, in the case of undertakings having thousands of metered consumers, amounts to an appreciable sum annually.

Perhaps one of the most beneficial improvements we can introduce into tariffs at the moment is the elimination of any connection of electricity charges with local rates. I am contemplating here 2-part tariffs based on rateable value, and it seems to me that it is a mistake to introduce in the minds of electricity consumers the idea of a tax so far as electricity supplies are concerned. A much fairer basis for such a 2-part tariff is admittedly floor area or cubic capacity.

CONCLUSION

In conclusion, I feel assured that the coming quarter of a century will eclipse the wonderful development that we have witnessed in the last 25 years. Given the will to succeed, there is no limit to the results which can be achieved in this industry, to which we are all proud to belong.

HAMPSHIRE SUB-CENTRE: CHAIRMAN'S ADDRESS

By S. HARCOMBE, M.A., B.Sc., Member.

"RESEARCH AND WASTE"

(*Address delivered at* PORTSMOUTH, *9th October*, 1935.)

It has been forcibly impressed upon me, for several reasons, that I should depart from the normal custom of choosing for the Chairman's Address some subject with which the Chairman is directly concerned, and to deal with one of general interest—not only to electrical engineers but to many others. While I anticipate a large amount of disagreement with the conclusions which I shall reach, I none the less hope that my Address will provide scope for some serious thought, with perhaps changed ideas regarding the future development of the uses of electricity.

Almost coincident with the formation of this Sub-Centre, two other decisions were made by the Council, decisions which to me appear important. These were:—

(1) To admit to Corporate Membership, after the usual qualifying experience, those applicants possessing university degrees in physics.

(2) To incorporate in the list of optional subjects for the Graduateship Examination, that of "Engineering Organization, Management, and Economics."

The first was brought forward by Mr. C. C. Paterson, during his year of office as President, and there is not the least doubt that he had had ample opportunity of assessing the value of such men in relation to the development and progress of electrical engineering.

The second was dictated to a large extent by the desire to encourage among the younger members a close study of the economics of electrical engineering. To this end prizes had been offered to Students and/or Graduates submitting the best paper on the subject of "The Relations between Economics and Engineering."

It has therefore appealed to me that my Address could very well leave the purely electrical, scientific, or mathematical aspects alone, and, bearing in mind that the expression "electrical age" is becoming more and more an appropriate description of the present times, to review what part the physicist and the economist have played, and might play, in electrical engineering. Previous chairmen have adequately dealt with the training of the electrical engineer and have emphasized the necessity for possessing a sound knowledge of physics and mathematics in order to become really efficient electrical engineers to-day. It is therefore unnecessary for me to deal with that aspect of the question. Further, such eminent men as Parsons, Ewing, F. E. Smith, and Paterson, have recognized that it is difficult, if not impossible, to say where the line of demarcation should be drawn between the physicist and the electrical engineer, and the recent decision of the Council is in accord with that view.

Let us first dwell on some aspects of research. We are frequently reminded of the expression "Art for art's sake." It would be equally true to say that research should be pursued for the sake of research. In the past this was doubtless true of the great majority of the investigations which really mattered; but in recent times both government and industry have come to realize what scientific research can do for the country and the world, and, as a result, research has become somewhat tainted with the atmosphere of commercialism, with its more insistent query "What is the use of it?" In the past the commercial results of research were generally incidental. The Davy lamp was really an accident, or, if you prefer, a by-product of an inquiry leading far beyond such a result, in spite of the vast commercial value of such a discovery. As art has been called to the aid of commerce, so also, in recent years, has research been harnessed to assist in the solution of the problems of this harassed world. It solves problems and creates them. It may lead to immense benefits, as through X-ray treatment, radio, and the cinema, or on the other hand it may lead to disaster, as in its application to warfare. The timid suggest a holiday, and the adventurous increased activity. He would be a bold person to prophesy in this realm, but it may not be out of place to quote from two leaders in engineering and science, honoured members of our Institution, who are now no longer with us.

Sir Alfred Ewing in his British Association address remarked, on the thinker's outlook towards mechanized progress, "Admiration is tempered by criticism; complacency has given way to doubt; doubt is passing into alarm."

And Sir Charles Parsons, in his Presidential Address to the British Association in 1919, said: "The possibility of the uncontrolled use on the part of a nation of the power which Science has placed within its reach is so great a menace to civilization that the ardent wish of all reasonable people is to possess some radical means of prevention through the establishment of some form of wide and powerful control. Has not Science forged the remedy, by making the world a smaller arena for the activities of civilization, by reducing distance in terms of time? Alliances and unions, which have successfully controlled and stimulated republics of heterogeneous races during the last century, will therefore have become possible on a wider and grander scale, thus uniting all civilized nations in a great League to maintain order, security, and freedom for every indi-

vidual, and for every State and nation liberty to devote their energies to the controlling of the great forces of Nature for the use and convenience of man, instead of applying them to the killing of each other."

It is clear that in this age of uncertainty one must attempt to direct research into definite broad channels. There are urgent problems calling for solution, and it is essential that scientific research on purely academic lines should be continued and fostered; for the past has fully demonstrated that it is from such work, apparently of no direct commercial application, that industries have been created and profitable fields opened out. All of us are familiar with the developments from the researches of Faraday, but not so familiar with those due to the investigations of Clerk Maxwell and Hertz, which lead through the work of Jackson, Marconi, and many others, to the immense wireless industries of to-day; nor to the researches of Joule and Kelvin on the porous plug which have meant so much to modern methods of food preservation, production of oxygen, and atmospheric fixation of nitrogen. During the past year or so Mr. Paterson has ably demonstrated to us here, and to many others throughout the country, what part the "free electron," the quiet discovery of the physicist, plays in the electrical engineering world of to-day.

We are all painfully aware of the word "economy," and many sins have been committed in its name. True economy implies the elimination of waste. It should not be confused, as some are apt to do, with the non-use of materials, but rather to the use of any material with the minimum of waste; and it is in this sense that I shall deal with it later in this Address. In many spheres we meet the war against waste. The medical world is concerned with waste of life and working powers; social workers with waste of young lives; and scientists and engineers with waste of material and energy. Surgeons and physicians now have available medicines and apparatus undreamt of many years ago, and it is estimated that the average life has been extended 10 years during the last century, in spite of the terrific rush of modern times. Efficient refrigeration and rapid transport have made the surplus food supplies of the world available for all countries where they are needed. Transport by road, rail, sea, and air, have made travel more speedy and cheaper. Communications have even more shortened time and distance, and the telephone and telegraph have passed into the wonders of wireless and general broadcasting, which was non-existent at the beginning of the present reign; yet millions now own wireless sets, while many more millions must have listened to the 1935 Jubilee broadcast in all parts of the world.

When Watt gave his engine to the world he had succeeded in reducing the fuel consumption from about 20 lb. of coal per horse-power to just over 5 lb., while to-day, through the genius of Parsons, steam turbines have reduced this even further to $1\frac{3}{4}$ lb., with consequent cheapening of power. The electric lamp of Swan's days using 4 or 5 watts per candle-power has advanced to one using less than 1 watt per candle-power, so that now, with the cheap power and efficient lamp, electric lighting, originally almost a luxury, is almost a necessity. These illustrations should help to distinguish between economy in material and ultimate cheapness of an article brought about by organization and mass production—a form of cheapness not without its disadvantages.

One definition of the aims of an engineer has been expressed in the oldest of our engineering institutions as "The art of directing the great sources of power in Nature for the use and convenience of man"; and when one examines the work of the great engineers of the past we are strongly tempted to amplify this definition by adding "not only for his own generation but also for future generations." A few examples may not be amiss—examples taken from modern times, with which we are more or less familiar. We in Portsmouth have been taught to appreciate Brunel, of Great Western Railway fame, whose many famous bridges remain as monuments to his greatness; we have been reminded during the past year of the great work of Telford in road engineering, and particularly of the magnificent road from London to Holyhead. We recall the work of Faraday, perhaps more his life, in seeking that "unity in nature" which must benefit mankind for all time. We are reminded too of Clerk Maxwell, who also put aside the lucrative temptations held out to him and diligently developed mathematically the ideas of Faraday, and so laid the foundations of modern wireless. And again one may well recall Kelvin's lament at the dissipation of energy in Niagara Falls, and his conviction that it was the duty of scientist and engineer to harness such energy for the benefit of mankind; would he not rejoice to-day at the Niagara peak load of 0·9 million kW with a supply to 600 municipalities!

It must have been in the spirit of these great engineers that the conception of the electrical grid system arose, not only in this country but in others. Such wise planning in other fields on a national and international scale would undoubtedly spare posterity the many difficulties which this country is now experiencing. Some countries have gone further and developed a gas grid, and we, in this country, know that, as a result of the long summer of 1934, and acute water shortage in many areas, there has been considerable talk regarding a water grid. And surely, we may ask, why not? There were immense difficulties in the way of the electrical grid, with such a vast number of supply undertakings involved, and such a wide variation in supply voltage, but they have been overcome, and the huge capital was obtained with no reluctance on the part of the public. We have seen an incomplete railway grid arise from the chaos of pre-war days, in spite of the great opposition of private interests. Thus we may yet see the engineer triumph over legal and private obstacles, and give us not only a water grid but also gas and coal grids.

The last hundred years have therefore seen the world endowed by the scientist and engineer with the most powerful means for the elimination of waste in all spheres, for the production of human necessities in immense quantities, and for the replacement of manual labour by machinery. The history student of the future may be able to judge how much better the world is for these advances; but we to-day can say with emphasis that it is not the fault of the scientist or

engineer if the world is not immensely better now than 100 years ago. To us in Great Britain, the early inventions of Newcomen, Watt, Trevithick, Arkwright, and others, placed the country pre-eminently ahead of all others, and Great Britain became the workshop of the world—the raw materials poured into this country, and the manufactured articles were exported to all corners of the globe. So arose the great cotton industry and others, and social conditions changed rapidly; and we know too well how the parliaments of those days had to step in and curb the cruel exploitation of labour. Now the world has advanced to the rapid transport over land, sea, and air, the unlimited communications of telephony and wireless, and production and preservation of food supplies in abundance. But these advances have no longer been the monopoly of Great Britain—science and engineering have been the servants of other countries during these years, and they have learnt to make for themselves those things Great Britain once provided for them. We realize it is so; we know how Germany before 1914 was rapidly capturing our markets; we know full well to-day how Japan is just as rapidly making inroads even in our colonies. It is therefore imperative that we should take stock of our position, and that we should see where and how we can help ourselves. (Lantern slides lent by the Research Departments of the B.T.H. Co. and the Metropolitan-Vickers Electrical Co. were here shown, in order to illustrate the advances due to electrical research.)

We now pass on to the next consideration, perhaps the main theme of this Address, namely the economics of the industry. My treatment of it may appear almost heretical to electrical engineers, but it is one which must be considered and I, personally, look to the young engineer to develop the reasoning and construct as did those great engineers to whom I have already referred. I am going to consider the problem of national economy in our fuel resources and the relation between gas and coal as bearing on the development of the electrical system of this country; and perhaps a suitable text would be the conclusion stated by Parsons, Beilby, Thelfall, and Redmayne, in their report some 16 years ago: "The national interests will best be served by that policy which will promote the widest adoption of scientific methods for the preparation and use of coal." This Sub-Centre is, I think, the only one of the Institution Centres or Sub-Centres not containing a coal area; latterly, too, the great warships and liners have changed from coal to oil fuel, and it would seem that we ought not to be interested in the problem. Indeed, I have often heard some such remark as "Why bother about coal; oil is now replacing it?" This attitude has been a contributory factor in my choice of subject.

We know that there is tremendous activity in certain quarters to urge the use of electricity at all costs; we have read papers ably presented, showing how electricity can be the most economic form of heating, and in this drive we see almost bitter, if not stupid, rivalry between the two great industries—electricity and gas—and between them the basic industry of both—coal—in a very desperate situation; desperate, not only for the shareholders, but even more for the workers in that industry. So acute is such rivalry that we find one of the great leaders of one industry, when presenting his annual report to the company this year, saying "It is essential for the purpose of maintaining a low price of coal that there should be free competition between the different collieries, so as to enable . . . undertakings to buy the most suitable coal as cheaply as possible"—an unfortunate comment from a concern enjoying almost the privileges of a monopoly. Nor can I appreciate the comment "With coal at 18s. per ton, the electrical heating proposition is somewhat difficult for the larger installations, but even at that price there is a large domestic field." Can any engineer contemplate with equanimity a reduction in the price of coal, when the actual coal-hewer gets the small sum of 3s. per ton for his work? No! we must seek other ways of producing cheap electrical energy for the consumer. This acute rivalry between the two concerns is to be deplored, and I plead for a healthier co-operation. It is true that this rivalry has led to the production of far more efficient apparatus—fires, cookers, etc., on both sides. Such co-operation has been achieved in other countries, which realized the importance of national economy in fuel, and we must admit that the talent of this country could achieve similar co-operation. In asking for such co-operation I do so not in the interests of either supply undertaking directly, but primarily in the interests of the country itself, and in the interests of the workers in the coal industry. It is with real sincerity that I say it is full time that we gave very serious attention to that industry, that we studied carefully and without bias the operations of the electricity and gas supply undertakings, and that we should determine what remedies are possible in making the fullest use of our basic fuel—coal—and to help those producing it. If anyone is in doubt regarding the necessity, let me recommend close consideration of the present state of the industry and then an appreciation of the remark made by one of our most prominent shipowners, the late Lord Inchcape—"It is no exaggeration to say that coal has been the maker of modern Britain; and that those who discovered and developed the methods of working it have done more to determine the bent of British activities and the form of British society than all the parliaments of the past 120 years." We may not wholly agree with him, but we must appreciate the force of his remark.

Let me again repeat at this stage that in what follows there is no attempt to present a case for or against the use of any particular fuel, whether it be electricity, gas, or oil, or for any particular system of using these forms of energy. Let others thrash out the respective merits of thermal storage or inlaid panel or tubular heating, and the numerous other alternatives. This address is not intended to deal with the economies in the use of fuel at the consumer's end, however meritorious they may be; and it has already been shown how, in the case of the filament lamp, such economy has been beneficial; but it is intended to consider economies in the production stages, and suggestions for the more efficient uses of the various forms of energy.

It has been estimated that the available water power of Great Britain represents less than 1 per cent of the total world water power, while our coal reserves are about

$2\frac{1}{2}$ per cent of the world's total reserves. The annual production of this country at present is 20 per cent of the world's annual output. With our present knowledge, these are our main power supplies, and the future will decide the question of harnessing the tides, atomic energy, or the internal resources of great depths. The figures given indicate that it is very necessary for scientist, engineer, and economist, to make the fullest use of these resources.

Under the electrical grid scheme it has been estimated that the units sold to consumers by 1940 will be 25 000 million; already returns show that the figure reaches 16 000 million, involving a coal consumption of over 11 million tons, with an average efficiency of 1·5 lb. of coal per unit of production, from which it is easy to show that the contribution of the coal cost to the production of 1 unit is about 0·1d.; while the thermal efficiency of the production, assuming a calorific value of 13 000 B.Th.U. per lb. of coal, is just over 18 per cent. The important conclusions to be drawn at once, therefore, are first that the coal cost towards the production of electrical energy is not the heavy item, and the consumer may well seek an explanation of why in some districts he has to pay as much as 1s. per unit for light, and why distribution on an average costs three times as much as generation; and secondly that there is a loss of over 80 per cent in the energy contained in the conversion to electrical energy.

On the other hand, the gas undertakings use about 17 million tons of coal per annum, and on an average produce about 70 therms of gas from 1 ton of coal, giving a thermal efficiency in gas alone of over 25 per cent. But, of course, in addition to the gas, there remain coke, tar, and other by-products, all of which are usable, so that an overall efficiency of conversion equal to about 70 per cent is achieved.

This contrast in efficiencies is perhaps striking, but none the less true, and it seems to me a matter of importance in the national economy of fuel that the lower efficiency should be avoided; and surely, as a result, there should be a cheapening of electrical power supply. It is useless to try to assess the responsibility for such a position, either on the electrical or gas undertakings; there are vested interests on both sides, even with antagonisms between leaders and workers in the respective concerns; and it is perfectly clear that a new outlook, a new psychology, is urgently needed. It may confidently be assumed that neither the real engineer nor the true scientist can be blamed for the position. And as I examine the possible uses of gas and electrical energy, with the enormous advantages the latter has in many spheres, it has struck me forcibly that the electrical industry may afford to be generous to its rival where there is still controversy as to the more useful form in a particular service.

Who can see a competitor to electricity in telephones, telegraphs, wireless, railway signalling, X-rays, purely local heating, and the possibilities of photo-electric cell devices; to electrically driven gyroscopes for sea and air, and radio direction-finding? What other power could have given us the marvel of our Institution and the American Institute holding a joint meeting in 1928 across the Atlantic; of the Jubilee celebrations and speeches being simultaneously shared in all corners of the world; and can it not now more than hold its own in the fields of lighting, motive power for works and factories, underground tube railways, and even in the railless trolley-buses? But there is still the keen struggle in the realm of heating, whether domestic, factory, or furnace, and also in railways. While the struggle has been going on to capture the heating demand from gas, the petrol bus has come along and ousted electrical tramways; yet for town use, or where such supplies were available, the electrical railless bus can very definitely hold its own against the petrol bus. It has been calculated that if the tramway system of a town like Manchester were abolished in favour of petrol buses, there would be a reduction in coal demand of 55 000 tons per annum, equivalent to 250 miners thrown out of employment in favour of others in foreign lands.

Yet this failure of the electrical industry may be remedied in the near future when the home production of oil fuel may be expended on the buses. Then the railways offer a big field for electricity, and the process of electrification will be gradual but none the less certain as the years pass. Here again one finds very important developments in the use of the oil-driven engine—with oil easily obtainable from coal—and there are now regular services with such trains, capable of speeds up to 80 m.p.h. Certainly the fuel cost of $\frac{1}{2}$d. per mile for such trains is remarkable and represents a decided advance.

It is in the application to heating that rivalry is most acute, and here the rivals to electricity are the solid fuels such as coal and coke, and oil and gas. Gradually, but again surely, the damaging effects due to burning the raw coal are being more and more appreciated. Sir Frank Baines, former Director of Works and Buildings at H.M. Office of Works, estimated the damage to buildings alone as a minimum of £2 000 000 per annum. Yet, though this damage is appreciated, the working man must use the raw coal as his cheap fuel while gas and electricity cost so much. It is useless to bring in difficulties of coal storage, cleaning of grates, etc., in discussing heating economies with people who have time to do such work but not the means to indulge in the comforts of gas or electricity. There is only one way to capture this domestic load with satisfaction to both sides, and this must be by a considerable reduction in the cost of electrical or gas energy to the consumer; and I cannot see a figure of $\frac{1}{2}$d. per unit bringing satisfaction to the great number of workers earning less than £3 per week. I know it is being done in many cases, but I also know how much disappointment has followed later. When the question reverts to thermal storage by water, and the distribution of heat by such means, there is little doubt as to which is the most efficient. Similarly with the huge industrial heating demand, the various forms of fuel are used, and each serves its purpose effectively. The real point is that the right fuel should be used in the right way, regardless of the vested interests concerned.

There is another aspect of the question which should commend itself to the electrical engineer, and electrical undertakings might do well to consider the same point. This arises from the difficulty of storing electricity, or,

it would be more correct to say at this stage, the utter impracticability of doing so (I am not considering thermal storage here). Thus, for instance, the peak gas load for Portsmouth is 14×10^6 cub. ft., of which 75 per cent is for cooking; on a calorific value of 450 B.Th.U. per cub. ft., and neglecting efficiencies for the moment, this would require a peak load of electricity supply equal to $1 \cdot 8$ million kW. If we credited electricity as being twice as efficient as gas, the peak load would be $0 \cdot 9$ million kW—the present peak load of the Niagara Falls power station. Now the present capacity at Portsmouth is 32 000 kW, 30 000 kW can be obtained from the grid, and 30 000 kW is to be added—a total of 92 000 kW. The additional requirement is enormous, and one may well ask whether it is worth it, and whether it would be beneficial ultimately. So the figures could be worked out for other areas, and it has surprised me how much stand-by plant would be necessary if electricity were successful in displacing gas entirely. It therefore does seem of importance from the national point of view for the electrical engineer to direct his attention to other channels.

It must be realized that there are two serious difficulties in the generation of electricity for heating; there is first the low efficiency of conversion of heat energy into mechanical energy. Parsons himself gave a maximum thermal efficiency of 27 per cent for the very large steam turbines, and about 21 per cent for normal large steam turbines. Secondly there is, as yet (apart from the thermal storage by water—admittedly an important factor), no satisfactory way of storing electricity so that the heavy peak loads may be eliminated, with resultant reduction in capital costs and overhead charges. Thence the non-partisan must deduce that gas scores heavily, and it seems to me no more than common sense that these advantages should be adequately used.

One more point. I find that the total capital of gas companies—private and municipal—is about £160 millions, and that the gas output is something like 200 000 million cub. ft. per annum, which on a heat basis far exceeds the estimated full capacity of the electrical grid in 1940. The total capital of the electrical undertakings is about £350 millions. Need I stress the rest? Surely the time has arrived for a healthy co-operation instead of an insane competition. There the matter is left for your consideration, while we return to the production side.

The trend in modern research is in two directions:—

(1) To produce gas and use it as the stage between the raw fuel and the steam in producing electrical energy, and

(2) To consume the raw fuel as at present in producing electrical energy, but in addition to aim at collecting the by-products, such as light oil, Diesel oil, and fuel oil, which are now merely consumed in the combustion chamber of the boiler.

The first method would undoubtedly lead to the production of gas-fired boilers, with resultant elimination of the storage and handling processes, which we now see in power stations; and also the elimination of dust and smoke common to such stations. Where gas and electricity supply undertakings are owned by the same people, as in some municipal undertakings, it should be possible to combine them in one works, gas production and steam-raising being treated in the same unit.

The second method implies that the large power stations should combine combustion with low-temperature carbonization—the raw coal is subjected to low temperature carbonization in retorts, so that the residual hot smokeless fuel is burnt direct under the boilers, while the gases and vapours evolved pass through condensing and scrubbing plant for the recovery of the tar and crude light oil, the residual gas also being burnt in the boiler setting. By this means 1 ton of coal might be expected to give 21 gallons of crude oil and tar, in addition to other by-products such as fuel oil and pitch. Thus, if it were possible to deal with the present 11 million tons of coal used in the generation of electricity, there would be available about 30 million gallons of crude oil and 100 million gallons of Diesel oil.

Various methods have been evolved of the second process—two in England—and developments should be interesting. It should be emphasized that the stages of this method are operated as a part of the boiler or other furnace setting itself, as in any low-temperature carbonization process; plant could be put down near or in the boiler house, with combustion of smokeless fuel, and residual gas produced separately.

Before the British Association in 1934, Prof. Baily read a paper on "Sources of Cheap Electric Power," his object being to show how the waste coal at collieries could be used with advantage to generate electricity, such small stations being connected with the grid system, which rendered such operations possible, and would make them economical. The application of method (2) would further improve such small stations, and one can even envisage electricity displacing coal for heating in the homes of the producers themselves. Instead of providing fuel or cheap coal, the more convenient form of energy, electricity, would be supplied cheaply.

Let us follow a little longer this use of the raw coal. Of the 200 million tons of coal used annually in this country, we find 40 million used in domestic fires, 70 million in manufactures, 13 million in railways, and some 20 million in and around the collieries; that is, something like 140 million tons are used in a very wasteful way. There are also the 30 million used by the gas and electricity undertakings, making a total of 170 million tons. If the whole of this were efficiently used in the manner indicated, there would be available 400 000 million gallons of crude oil and 1 500 000 million gallons of Diesel oil, from our own coal supplies; whereas the present total consumption of petrol is just over 1 000 million gallons. Of course one does not imagine it possible to use the whole of the coal in this way, nor that so much coal would then be required, but the inference is obvious. That it is not an empty dream may be realized by noting that on the 26th April this year the first trainload of 100 000 gallons of oil from low-temperature carbonization was sent to the Imperial Chemical Industries plant at Billingham for treatment by hydrogenation

and conversion into 100 000 gallons of petrol. Such development, properly directed and used in the interests of the fuel economy, the country, the producer, and the consumer, would have tremendous advantages. Among them would be (1) the supply of clean fuel—gas or electricity—at much cheaper rates, both to the workers' homes and to factories, without the need for storage or handling dirty coal; (2) the use of electricity as the motive power on railways; (3) great reduction in smoke and soot pollution, and (4), above all, an abundant supply of oil for home consumption, rendering us independent of external supplies. The coal would be taken as required, split up into its constituents, and there used in the most efficient manner. Gas would be used to deal with most of the heating, electricity for the motive power of works and railways, for lighting and small heating, and for furnaces, while the oil would be expended on means of road, sea, and air transport.

Coal hydrogenation at Billingham now provides 45 million gallons of motor spirit per annum—about $3\frac{3}{4}$ per cent of the total consumption—and ultimately will reach 90 million. The present plant employs 1 900 miners and 1 000 plant employees, so that, to make ourselves independent of external supplies, work would be found for about 70 000 men, and apparently with a capital expenditure (judging from this year's report of Imperial Chemical Industries) of about £75 000 000, figures quite commensurate with those in the development of the grid.

There is not time to consider any financial aspects or to show how electricity can be applied to agriculture, egg production, hay-making, and intensive culture of crops, so that our small available acreage may better serve our dense population, and even to the culture of areas previously inaccessible. But I trust my objects have been achieved in showing that the electrical industry has available fields which are open to no other competitor, that it can be generous to its competitors in other fields, that it still has unexplored fields open to it alone, and that in the interests of the country, in securing the greatest economy in our basic fuel coal, it should seek co-operation with its competitors. Only in some such spirit will it be possible for the annual consumption per head in Great Britain to rise from 245 units to anything approaching Canada's figure of 1 500 units.

Is the co-operation and development at which I have hinted an idle dream? If so, it has been shared with eminent electrical and gas engineers, such as Parsons, Wordingham, and Dugald Clerk, to mention only a few. I refuse to believe that it is not feasible. It is useless to try to run this twentieth-century world with nineteenth-century ideas. We cannot afford to think in terms of industries, but of one greater unity to which each must be subordinate, and if the scientist and engineer approach these problems in this spirit and with the vision and honesty of purpose revealed in the lives of such men as Faraday and Clerk Maxwell, then, and then only, will the edifice they construct be worthy of the foundations so well and truly laid.

DUNDEE SUB-CENTRE: CHAIRMAN'S ADDRESS

By J. F. BUGLASS, Associate Member.

"MODERN STAGE LIGHTING"

(*Address delivered at* DUNDEE, 10*th October*, 1935.)

I have selected modern stage lighting as the subject of my address, and I propose, in so far as time will permit, to deal with the trend of modern practice and some of the principal developments which have taken place in this highly specialized department of electric lighting within the past few years.

It is possible that in few other branches of electric lighting are the requirements more exacting, and the demands made upon the resource and ingenuity of the electrical engineer more severe, than in the effective lighting of the modern stage. In many cases those responsible for the lighting arrangements are perpetually being urged by the playwright or producer to provide them with more and still more novel or beautiful lighting effects. This has resulted very largely in this branch of electrical engineering, where maximum effect and fullest adaptability to all possible requirements are a consideration of importance, being carried out by specialists in this class of work.

Before proceeding further, it might be advisable for the benefit of those who are not familiar with the general layout of the modern stage, or who do not know the terms used in the theatrical world for the equipment and apparatus used in connection with or upon it, to deal briefly with the more important of these so that it will be easier to understand what I have to say.

What is really the centre of the whole system is the "acting area," which is, as the name implies, that portion of the stage, in view of the audience, upon which the action takes place. On each side of the acting area the stage is extended to form what are called the "wings," which are concealed from the view of the audience by scenery and the sides of the proscenium arch.

In the wings, well out of sight of the audience, and situated some distance above the stage-level, are the "fly floors" or "fly galleries"—commonly known as the "flies"—stretching from back to front or what is termed "up and down stage."

Right over the stage, and often just under the roof, is the gridiron or "grid," which is a large steel or timber framework, usually as large as the whole stage, the purpose of which is to carry all the tackle and other gear for raising and lowering the scenery. The ropes for this purpose are brought down to the fly floors, where the men responsible for operating them are stationed. Various gangways called "bridges" run across or up and down stage and at various heights above it to give easy access to the timbers, rollers, etc., carrying the scenery, or to the lighting battens and fixtures.

The scenery used upon the stage is of several different types, according to the purpose for which it is required. It may consist of "flats," which are light wooden frames covered with scenic canvas and suitably painted, "cut-out pieces," which may be used to represent, say, a tree or house in front of the other scenery, or "cloths," "backings," or "borders," which are usually unprovided with a frame work but hang from a roller or spar which is suspended from the grid at the required height. Another type of flat or cut-out piece is called a "ground set" or "piece," being of no great height and lying across or along the stage to represent, say, a hedge or wall. When flats or other scenery are placed in the wings they are usually called "wing flats" or "wing pieces."

Braces or struts are used for supporting the flats or other framed scenery, and where flats are placed with their edges together they are usually lashed up behind with rope lashings over cleats attached to the frames.

It will be admitted that the scenery, although it may have some semblance of solidity when viewed from the auditorium, is of little use to the stage electrician for the support of his lighting fixtures, and though the scenery were rigid enough to serve this purpose the lighting gear would only hamper and delay the scene-shifters in setting or striking the scene.

To get back to our subject again, I think we are all agreed that the principal object of stage lighting is to light the stage, but this is by no means all, as in many cases the stage lighting is used to darken the stage or parts of it, and so produce fixed or varying colour and tone values of the lighting and thus supplement the illusion and assist the actors.

To make my point clearer, let us take the example of, say, an interior scene, a room with a table with the cloth disarranged and a knife lying on the floor beside it. The room is brightly lighted with what represents warm sunlight streaming in through a window from a floodlight outside. To the audience this scene will suggest a perfectly simple explanation, that the cloth had been accidentally disarranged and that the knife which was upon it had fallen to the floor. But let us "black out" our sunlight and throw a beam of dim cold moonlight through the window to fall on the knife on the floor. What is the reaction of the audience now? They feel that some grim tragedy has been enacted and they strain their eyes to pierce the gloom of the chamber to see if they can discern a huddled mass lying somewhere in the shadows.

You will appreciate my point and will, I think, agree that there is justification for claiming that to light a stage in a manner which will assist and not detract from the value of the production from a spectacular point of view is a somewhat exacting task. The sources of stage

lighting may be broadly classified under several different heads—footlights, battens, wing floods, fly floods, ground lengths, and spotlights. All those light sources are usually so arranged that coloured gelatines can be used with them, and they may be connected, if need be, either singly or in groups through the dimmers so that the intensity of the light may be varied if required.

Before the introduction of the high-power focusing or projector-type gasfilled lamp, the theatrical producer was somewhat restricted in his selection of available positions for high-intensity spotlights and floodlights. Having only arcs available for this purpose, he had to place them at points easy of access for trimming purposes. The removal of this handicap has enabled the producer to make full use of the increased flexibility of the lighting system and place his spots and floods in exactly the positions he had wistfully wished to have them in former days. It was thus possible to make one light, placed exactly where it should be, do the work of two or three placed in positions which were, after all, only a compromise. It is, therefore, only natural that we find the producer, in his never-ceasing quest after effect, only too eager to avail himself of the greater resources which the lamp manufacturer and electrical engineer have placed at his disposal.

Of all the sources of stage lighting it is the footlights with which the members of the audience are probably most familiar, as they lie along the front of the stage either above stage-level and shaded from the auditorium side, or sunk in what is termed a "lighting pit" below the level of the stage, in which case they are provided with reflectors to throw the light where it is required.

The footlights, or "floats" as they are sometimes called—a survival of the time when they consisted of a row of wicks floating in oil—were probably among the earliest sources of artificial lighting on the stage, but in many modern productions the footlights play only a secondary role, being used, as we might say, to wipe out the minor shortcomings of the other sources of lighting.

The second lighting group on our list—the battens—are similar in type in many cases to the footlights, but are usually suspended across stage and above it, concealed from the view of the audience by what are called "masking borders." The battens, like the footlights, are really a row of floodlights, often of low or medium power, each one throwing a fairly wide-angle beam so that the intensity of the light is more or less uniform from this source over the entire width of the stage.

Our third lighting group—the wing floods—are situated in the wings, and vary, according to the requirements of the production, from a single floodlight at each side of the stage to a complete row of 20 or more mounted one above the other. As there is a possibility of the wing floods being masked by the wing scenery if fixed in one position, they are frequently mounted on a wheeled trolley so that they may be placed in the most effective position to suit the particular stage setting. In some of the larger theatres where elaborate productions are staged, spotlights and lanterns for special effects are mounted along with the wing floods on the trolley, the whole forming what is called a lighting tower. This arrangement is very effective and enables a complete battery of lighting effects to be moved about at will.

Another system of floodlights, termed the "fly floods," are often fitted near the fly galleries, either on the fly floor itself or on perches nearby. This is a very effective position as it enables a beam to be thrown at a good angle on to the stage, and it has the added advantage that floods so situated, being higher above the stage-level than the wing floods, are less liable to have their beam or light cone masked by scenery and they therefore, generally speaking, have a larger zone of cover.

The fifth source of stage lighting on our list, and the last of what might be called the true flood variety, are the ground lengths or ground battens. These consist of a row of lights somewhat similar to the footlights or main overhead battens, and are usually situated well up stage where they are generally concealed behind a ground set, if one is available. The purpose of these ground lengths is to give increased lighting for a back cloth or some particular section of the up-stage scenery. In most modern well-equipped stages these lengths are sunk beneath the stage-level in a lighting pit which can be closed up when the lighting from this position is not required, thus leaving the whole stage free for action. Where no lighting pit is provided the battens are generally mounted on low trolleys which can be run on to the stage from the wings and set as required.

Another effective source of lighting, called the "acting area flood," is frequently used in modern productions. It is hung directly over the acting area and throws its light vertically downwards on to the stage. The position of this light enables it to neutralize any shadows which sometimes cannot be altogether eliminated from the other lighting positions. As the acting-area flood is sometimes focused to give a narrow-angle beam approximating more nearly to a spotlight it might sometimes be included in the latter category, and for this reason I did not include it in the list of floodlights proper. It is sometimes advisable to have the acting-area floods fitted with spill shields to reduce as far as possible secondary side reflections, as there is a risk—unless the flood is hung well up behind a masking border—of the light being thrown over the front of the stage into the auditorium. It is good practice to have, as a precautionary measure, detachable spill shields which can be fitted to any or all of the flood lanterns if need be, as occasions sometimes arise where the spill from a flood—otherwise trained in the proper direction—may upset the light value of some other part of the setting or pass over to the auditorium.

There is another type of lamp, known as a "horizon lamp," which can also be included under the flood category. Its principal purpose is to illuminate stage horizons or back cloths where great spread of light and covering capacity is often required. A well-designed horizon lamp should give an angle of spread of approximately 180 degrees. This great covering power enables it to be placed well up stage without impairing its efficiency.

The lighting sources I have so far dealt with may all be more or less classed under the category of floodlights, i.e. lanterns with a somewhat wide-angle beam giving a uniform light intensity over a comparatively large area, but there is another type of projector equally important for its particular purpose and designed to throw a narrow-angle beam of high intensity over a somewhat restricted area. This is the spotlight.

Spotlights may be fitted in any of the flood positions already mentioned, but as in many cases the spotlight is required to keep the actor covered as he moves about the stage the mounting should allow of universal movement. Where spotlights cannot be fitted at stage-level or on fly galleries or bridges, special perches must be provided for the operator.

Additional lighting of the stage is sometimes provided by powerful spotlights mounted in the auditorium, either at each side of and outside the proscenium arch, or in front of the circle. They are also occasionally attached to a framework suspended from the ceiling of the auditorium. These auditorium spotlights are usually of the fixed type, the presence of an operator not being desirable as it would tend to distract the audience.

I have so far dealt with what might be termed the main lighting sources on the modern stage, but in most productions now there are usually secondary lighting requirements to be allowed for, such as fire or hearth floods, standard lamps, etc. It is also frequently found desirable to have small or "baby" floodlights and spotlights mounted to lighting points which cannot be reached by the main lighting units. These secondary lighting sources are frequently concealed behind scenery or stage furniture.

Although I have dealt with the various lighting sources so far as single units or battens, it will be understood that, where a large stage has to be effectively lit, these units or battens must be multiplied, so that we may have footlights—three or four batten rows above (at varying distances up stage)—two or three floods at each wing and on each fly gallery—several ground lengths—and anything up to a dozen spots. Needless to say, of course, these would not all be on at one time, but they are available for use during one scene if required.

I have, I think, covered briefly the broad general arrangement of what may be termed the "straight" lighting of the present-day stage, but it will be obvious that more or less extensive modifications must be made to meet the requirements of special productions.

For what we may call the more spectacular production a lighting scheme of greater complexity is frequently demanded, necessitating the use of special-effects projectors, and other projection devices. Amongst the most important of the latter, and one which has perhaps assisted more than any other single piece of apparatus to enhance the illusion on the present-day stage, is the cloud machine. It is obviously leaving much to the imagination of the audience if, in a storm scene at sea with full wind, thunder, lightning, and rain effects, the clouds and billows on the back cloth are stationary. The modern cloud machine has altered this, and it can produce the effect of different strata of cloud moving in various directions across the skies, or of tossing billows, in a realistic and convincing manner.

Simply described, the cloud machine, which may be suspended over the stage near the acting-area flood position, or further down stage just inside the top of the proscenium arch, or, if desired, behind a suitable ground row, consists of a high-power projector lamp surrounded by a system of projection lenses, diapositives or slides in frames, and movable mirrors. The whole assembly of lenses, slides, and mirrors, is caused to rotate, by a small motor suitably geared, at a constant or varying speed round the central lamp. The images on the diapositives, which are usually prepared from actual cloud photographs, are thereby projected on to the mirrors, which are at such angles that the images are deflected on to the surface of the back cloth. As the machine slowly rotates, the angles of the deflecting mirrors are automatically changed in a predetermined sequence so that a very realistic effect of cloud movement is produced.

To obtain the maximum realism from the cloud machine it is desirable to have the surface upon which the projection takes place in the form of a cyclorama, which in its simplest form consists of the back cloth or the back wall of the stage curved round and forward at the wings, the curvature being preferably concentric, or nearly so, with the track circle of the deflecting mirrors. This ensures that the length of projection is constant throughout the whole arc of travel, with consequent fixed size of image. It is obvious that if the projection took place on a flat surface like an ordinary back cloth, the clouds in their travel from wing to wing would decrease in size as they neared the centre and increase again as they receded from it.

It will, I think, be agreed that the sphere of the cloud machine lies more in the direction of the spectacular production as, although it might assist the illusion to a certain extent in a "straight" play, there is risk of its projected cloud movements distracting the attention of the audience from the action of the stage.

It is only natural that, the principle of projection having been found so successful in the case of the cloud machine, it should have been tried out in other branches of scenic technique, and a good deal of experimental work has been carried out in the direction of the projection of architectural and other scenic effects upon plain flats or cloths.

It can be easily understood that however capable the designer, the scenic artist, and the stage carpenter may be, they are confronted with considerable handicaps when they have, after all, only canvas and paint as media to work with, and in the majority of cases the results leave something to be desired. In, let us say, the representation of the interior of a large church or cathedral it is almost impossible to convey the "atmosphere" to the audience to such an extent as we should like.

The question of architectural projection is unfortunately not so simple as the cloud-motion projection from the cloud machine. Architectural projection must take place upon a flat surface, and as it is essential that the perspective as seen from the auditorium must be correct it is not possible to use photographic diapositives, so that the latter must be prepared by hand and suitably corrected to compensate for the errors of projection.

A class of lighting appropriate for the production of the mystic or fantastic type has been placed at the disposal of the producer by the use of the ultra-violet rays. The stage is flooded with ultra-violet rays from suitable projectors of either the mercury-vapour or tungsten-arc types to which filters have been fitted to cut off as far as possible all the luminous rays. Although the stage is flooded with ultra-violet rays it will appear to the members of the audience to be dark or nearly so. If, however, the faces of the actors are made up with grease

paint in which some substance capable of fluorescing under the rays has been incorporated they will show up, being apparently rendered self-luminous. Any costumes, scenery, or properties, treated in like manner will also be rendered luminous.

The question of colour-changing and blending was one which, although in use from the earliest days of electric stage lighting, appeared until recent years seldom to have received the attention its importance merited. Little or no effort was made to standardize colours, and the question of the most appropriate tints and their densities was more often than not left to the operator on the perch, sometimes with hair-raising and devastating results. It is pleasing to note, however, that this unsatisfactory state of matters has now been very largely remedied and the question of colour-changing and blending and the selection of the most appropriate tints is receiving the attention which its importance in most stage-lighting schemes merited.

The auto-selective system of stage lighting and colour blending has assisted to a marked degree in eliminating the risk of error due to the human factor, and in it the producer has at his disposal a system whereby he can test out innumerable colour combinations beforehand until he has the exact tints he requires, and by the use of a pre-set control panel he can fix these so that they can be repeated in the required sequence without risk of variation due to operative errors.

The introduction of magazine colour battens and projectors has also materially assisted in reducing the labour of the stage electrician and also the worries of the stage manager. It will be readily understood that when a production requires frequent and more or less complicated colour-changes during the course of a performance, and where these have to be carried out by each operator on the perch beside his projector, there is a serious risk of something going wrong, unless the operating staff is thoroughly conversant with the lighting and colour plot with its numerous cues. There is a prompter in the wings to assist the actor if he has a lapse of memory, but usually there is no provision made for prompting the projector operators; should occasion arise for this I am afraid the prompter's voice would be heard all over the theatre.

The possibility of a hitch due to the foregoing cause may now be obviated, as the colour-changing at the projectors and battens can, by a system of remote control, be carried out by the stage electrician at his station at the stage switchboard. The simplest method of remote control has two operating solenoids provided at the projector to deal with each colour—one solenoid to move the colour screen into the beam and the other to withdraw it. As the colour screens with their gelatines and frames are carefully balanced, the solenoid current consumption is very low, the energy consumed in some cases not exceeding 10 watts per solenoid.

The remote-control colour-magazine principle has also been adapted with success to the battens and floats, so that they also may be under the direct control of the stage electrician.

It will convey some idea of the extent of the installation for the lighting of a large modern stage if I give some details of that at the Royal Opera House, Covent Garden. This installation was remodelled and extended last year, so that the details may be taken as typical of the most recent practice in the lighting of a large modern stage suitable for the presentation of the largest spectacular productions.

The total connected load of the stage amounts to approximately 850 kW, and the lighting load is made up as follows:—

Cyclorama lighting 148, 1 000-watt flood lanterns
Horizon lighting (at foot of cyclorama) 72, 500-watt flood lanterns
(Both those lighting groups are divided between blue, red, and green, in the approximate ratio 8 : 3·4 : 3·4)
(The area of the cyclorama surface to be illuminated is approximately 15 000 sq. ft.)

In addition to the above there are:—

Five rows of overhead battens with 1 000-watt acting-area floods fitted between them
Twenty-four special-effects lanterns (on bridge) with a combined flood and spot batten underneath
Two 3-tier lighting towers with 1 000-watt spot projectors fitted one at each side of the proscenium opening
Three 1 000-watt spot projectors with electrically controlled colour magazines (concealed in dome of auditorium)
Ninety-two socket points for portable lighting.

Before concluding I should like to touch on several points in connection with the design and construction of the stage-lighting apparatus with which I have dealt. In the design of stage-lighting fittings it is essential that a clear understanding of the conditions under which these fittings are to operate must be in the possession of the designer if he is to produce a range of fixtures which will give trouble-free service.

It may be something of a surprise to many to know that, on occasion, what we might call the "upper works" of the stages of some theatres can be very damp. This is not necessarily due to any shortcomings in the weather-tightness of the roof but is more probably caused in most cases by the moisture-laden atmosphere in a crowded auditorium being carried through the proscenium arch and up into the region of the grid, where it is condensed on the exposed steelwork of roof trusses and other fixtures. It will be readily understood that this moisture can in most cases easily find its way down and lodge on battens and other lighting fixtures. It is advisable, therefore, that the outer casings of all such apparatus should in every case be made of lead-coated or galvanized sheet-steel of ample thickness to give the required mechanical protection and rigidity and eliminate all risk of distortion due to the heat of the lamp. The upper surfaces of all fittings should also, wherever possible, be either rounded or sloped so that any moisture dropping upon them would run off. Any crevices or pockets where moisture might gather should also be carefully avoided, as sooner or later there is a possibility of its finding its way inside the projector where it is evaporated by the heat of the lamp with only too often dire results to the insulation of the lamp-holder or internal leads. Needless to say it is necessary, while still giving full con-

sideration to the points I have mentioned, to provide liberally for the ventilation of the interior of the lantern; such ventilation need not, in a well-designed unit, impair the drip-proof features.

A point of importance, second only perhaps to the design of the stage-lighting fittings themselves, is their method of attachment to the stage structure. The important points to be kept in mind in this respect are, in the case of isolated spot or flood lanterns, wide range of movement to cover effectively the largest possible zone, and maximum rigidity so that vibration due either to action on the stage or to the movement of the stage staff on the fly galleries and bridges is not transmitted to the lighting projectors. It will easily be realized how a medium- or long-throw beam magnifies any movement of this kind. We must bear in mind that our endeavour should be to conceal from the audience as far as possible the source from which the light is coming, or even in many cases the fact that there is any source of light at all—we should like them to take it for granted. The tense moment when the villain stamps across the stage is obviously robbed of some of its dramatic effect if his own particular spotlight is dancing round him like a luminous jelly.

I should have liked before closing to have touched on what we might call the secondary or auxiliary apparatus necessary in connection with a complete and up-to-date stage installation, viz. switchgear, dimmers, and those other appliances doomed, like the stage staff, to toil unseen; but considerations have compelled me to restrict the scope of this address to the covering—in, I am afraid, a more or less sketchy manner—of a smaller field.

SHEFFIELD SUB-CENTRE: CHAIRMAN'S ADDRESS

By F. GILBERTHORPE, Associate Member.

"ELECTRICITY AND STEEL"

(*Address delivered at* SHEFFIELD, 16*th October*, 1935.)

It would be difficult for anyone unacquainted with everyday events in steelworks to realize the remarkable progress that has been made, electrically, during recent years, or fully to appreciate the importance of the position which electricity is now able to assume in the varied processes associated with the manufacture and treatment of steel. Whilst this position is only in line with that attained in other similar industries, its importance is emphasized in those sections, such as steel manufacture, where the introduction of electrical methods of operation and control has revolutionized our ideas of production and has made possible a new conception of working conditions.

The use of electrical power, of course, has been gradually extending for a considerable time in mills and machine shops until, in the more modern works, it has entirely superseded other alternative methods of driving, with consequently improved efficiency and greater output; but by the application of the latest developments in electrothermal practice to melting, re-heating, and treatment generally, together with the electrical control of nearly all operations in the works and in the laboratory, the electrical engineer has enabled the metallurgist and steelmaker to achieve almost unexpected results in the quality and uniformity of the product.

SHEFFIELD STEEL

The Sheffield district has earned, through the centuries, a world-wide reputation for high-class steel, and from the earliest times the name has denoted quality. Laneham, writing in 1590 (two years after the Spanish Armada), said that: "women's wittes are like Sheffield knives, so sharp they will cut a hair," whilst another writer of the same period offers the advice " a right Sheffield knife is best," " right Sheffield," even at that remote date, being synonymous with excellence. But earlier still, more than 200 years previous to this, as shown in the poll-tax returns of 1379—out of a recorded population of 529 there lived in Sheffield 37 smiths, 5 cutlers, and 3 arrowsmiths, sufficient to form that nucleus of skilled craftsmen from which there emerged, gradually and in direct line, those steelmakers of the 18th and 19th centuries whose names became so renowned, and who laid the foundations of our present commercial and industrial position.

It may be interesting to note that the localization of the steel industry originally in this particular district is attributed, not, primarily, to the adjacent coalfields—vital as these proved to be at a later period—but to the undoubted ability of the local craftsmen who, it is stated, " possessed exceptional skill in the handling and working of steel."

ATMOSPHERIC CONDITIONS

The history of the steel industry—intensely interesting as it may be to those who know the Sheffield district, or who have had a lengthy association with steelworks—is not our concern at the moment; there is, however, a second and more recently acquired reputation, which we cannot altogether ignore, and which the city has gained owing to its prevalent surrounding atmosphere of smoke and the flare of its furnace stacks. There is not much occasion for pride in the fact that a locality can be recognized afar off by its smoke-pall in the daytime and its glare in the dark; nor is the idea a modern one, for we are told that 4 000 years ago the children of Israel wandered in the wilderness following " a pillar of smoke by day and a pillar of fire by night." Evidently a change of outlook is overdue.

It is customary to regard these unhealthy conditions as an indication of industrial activity, and as such they must, perforce, continue to be tolerated until it is possible to remove them and to substitute an atmosphere more wholesome and pleasant. Various attempts, of course, are being made to amend matters; for example, by authorized smoke inspection, and the limitation of smoke emission, or by modification in the design of furnaces where fuel is to be used in the form of raw coal. The opinion has been expressed by competent authorities that such schemes for smoke abatement may be considered merely as palliatives, and probably the chief source of the trouble—the burning of coal under unsuitable conditions—will have to be dealt with still more drastically before any complete remedy may be expected. The position, on the other hand, may not be quite as hopeless as we sometimes imagine; indeed there are definite indications that it is already improving to some extent. From a recent Report on Atmospheric Pollution we have confirmation of the opinion that Sheffield is by no means as dismal a place as various critics have implied. The official figures show that even the worst areas compare very favourably with several districts of London, and with similar towns in Lancashire and the Midlands.

There are many contributory causes; even the domestic fire is not without blame. It is usual to assume, however, that the steel-works are mainly responsible for the unhealthy conditions, and thus the matter becomes of some importance to us, as electrical engineers, because we realize that in the conversion to electrical power generally we have a practical solution of the dual problem of smoke elimination and the production of still higher quality in steel. In some instances the two are very closely related; for example, in the re-heating of certain types of steel where a smoky furnace is sometimes con-

sidered to be essential in order to prevent surface decarburization. Smoke emission would appear to be unavoidable, therefore, if the material is dealt with in the older type of furnace. In such cases, where the sympathy even of the smoke inspector has to be invoked in the interests of quality, there is a clear field for the more extensive application of electrical furnaces, and, apart altogether from the question of the smoke nuisance, the facilities which are readily available ensure precise control of furnace temperature. In addition it is possible to maintain a reducing atmosphere inside the furnace chamber, and so to prevent oxidation of the steel surface and the consequent effect which is usually termed " soft skin."

ALL-ELECTRIC STEELWORKS

This is a typical instance and it indicates some of the advantages which may be claimed in support of our argument for more complete electrification, for although there has been an enormous increase in the power demand, and the range of application has been extended to include all main drives and auxiliaries, steel-melting and various types of furnaces (particularly for special work or limited output), still there has been no serious attempt to displace the larger type of coal or gas furnace, and we have yet to see the general introduction of electrical furnaces of large capacity for re-heating purposes in the mill and forge. But it is already possible to visualize the all-electric steelworks, which will be entirely independent of other sources of power or other kinds of fuel. In the case of the better class of product, the higher-carbon and special alloy steels—where accurate and consistent results and a definite standard of quality must not be sacrificed to bulk of output, or where close scientific control is essential to meet increasingly more difficult and more rigid specifications—it can be shown not only that electrical methods are indispensable technically and practically, but that the use of electrical power for all purposes may be justified by the only crucial test in a commercial world, that of economic advantage. Much depends, of course, upon the local conditions of working; the question of intermittent or continuous operations, and other circumstances which may be peculiar to the works routine, but the chief factor governing the more general use of electrical power is now, more than ever, the actual cost per unit of power used.

POWER SUPPLY

The question of power supply is much too important, and too controversial, to be discussed in detail in the present survey, as it would necessitate amongst other things an exhaustive review of all the reasons for and against the operation of private generating plant as compared with the acceptance of bulk supply from an outside undertaking.

It must be admitted that few electrical engineers in charge of steelworks plant would willingly sacrifice the numerous advantages which are conferred by the running of a works power station. It is also true that, given favourable conditions, the working of such a station may be a sound policy, particularly in view of the fact that comparatively small boiler units and turbo-generators are now available with guaranteed efficiencies not far removed from those obtained in the latest superstations. Unfortunately in most steelworks the load is neither steady nor continuous, and the load factor (which may finally determine the whole question) is frequently much too low to justify the continuous operation of generating plant or the capital outlay involved. Other factors which may be dependent in some degree upon geographical position, such as water supply, fuel transport, and facilities for ash disposal, are obviously very important, but, as they are common to all schemes which include steam-driven plant, and are generally recognized, they need not be emphasized here. Special circumstances, however, which favour a private station may apply when the works are outside an industrial area, or where large quantities of steam have to be provided for process purposes; where there are special privileges regarding fuel; or where waste heat and other local conditions are likely to assist in the reduction of working costs.

Whilst coal- or gas-fired furnaces are still being used for steel-melting, re-heating, etc., a certain proportion of waste heat may be available for service in steam generation, or in the form of gas for driving generators, but the whole problem of waste heat may become so misleading, and the advantages so doubtful, that constant care is necessary in order to avoid the continuance of some compensation schemes after they have passed below the limit of efficiency. Instances may have occurred where the idea of power generation from waste heat has been advanced as sufficient reason for retaining some sections of plant which would be otherwise condemned and discarded. Obviously, under ideal arrangements in a modern works there should not be much waste heat, and in many cases the term must be considered either a misnomer or an indication of inefficient plant operation or design. Inevitably, as electrification proceeds, this secondary source of power will tend to diminish automatically, and it should ultimately disappear when the conversion is complete.

Whether, in any particular works, the conditions lend themselves to the generation of power, or whether the local authority may be able to offer more advantageous terms, are questions which can be determined in each case without any extreme difficulty, provided only that the relevant data are obtainable with sufficient accuracy. The essential purpose of the investigation, however, will be the provision of power at the lowest possible cost, and, in an industrial district such as ours, the majority of the steelworks, even the largest concerns (as indicated by recent events), are fully aware of the difficulties of the position, and, once having satisfied themselves that they cannot produce power so economically, they are quite content to allow generation problems to remain in the hands of an outside authority. This should not, of necessity, imply that a matter of such vital importance to industry is thereby placed completely out of the control of the works. Direct representation, at least by large consumers, or groups of consumers, should be possible on any local board or committee, to ensure close contact and co-operation between all the parties concerned.

The basis of charging for bulk supply, in order to encourage the full use of all the available power, may have to be modified in those cases where restrictive clauses,

such as maximum-demand time limits, are likely to restrain or embarrass the consumer. Although the elaborate precautions taken may safeguard a supply authority, and allowances are nominally conceded to the consumer for his assistance, the effect, commonly experienced in practice, is a tendency at times to curb or limit the use of power in the heavier units of plant. Possibly the "all-in" tariff, graded to stimulate an expansion of load, would in every case be the more practical basis, and would be more calculated to promote increased consumption. It seems fairly certain that the maximum-demand system has not been of much assistance in extending the use of electrical furnaces of, say, the arc type. The conditions during the melting period require a very heavy input of power for some hours, followed by a reduction, probably, to half load over a considerable period while refining takes place. These are just the conditions deliberately to be avoided by a consumer where payment is based upon a peak demand limited to 20 or 30 minutes, and it is thus evident that a further revision of the basis of such tariff charges must be considered unless these restrictions are to be allowed to interfere in the case of arc furnaces and other loads of an intermittent nature.

In steelworks there has always been a certain amount of fluctuation of activity from one department, or section, to another, and this has been further accentuated by recent trade conditions. Urgent orders to be completed in record time, and orders for limited quantities of special material, are frequently received and necessitate the re-starting of machines, or portions of plant, usually on very short notice. It is under these circumstances, where intermittent services are essential, that it is possible to appreciate the convenience of electrical operation in every section of the works; the ability to start any individual machine—or the largest furnace or mill—by merely closing a switch, may determine sometimes not only the taking of an order but its completion at minimum production cost.

ELECTRICAL POWER IN THE FORGE

These conditions may be exemplified in forge practice where, normally, it is necessary to light up boilers and raise steam many hours before the hammers are to be put into commission; or some of the boiler furnaces may have to be "banked up" during the intervals when they are not actually producing steam. The heat losses in boilers and steam services, in addition to the labour expense, may be computed and, together with the cost of fuel, water, maintenance, ash disposal, etc., they form a substantial figure for steam supply in the total expenses.

It is interesting and instructive to make a comparison between this and an alternative method which is adopted in some works where steam generation has been eliminated. Hammers of the largest sizes, and of modern design, arranged to operate on compressed air at about 60 lb. per sq. in., are supplied from air compressors directly coupled to standard-type motors. Automatic pressure control ensures efficient working, and air is compressed and delivered to the hammer only as demanded by the material being forged. As the compressors are situated quite close to the hammers, the transmission losses—which are most important, of course, in connection with compressed air—can be reduced to a very low figure. In the case of small power hammers the compressor, motor, and hammer, are combined to form one unit; the air—compressed to about 20 lb. per sq. in., and while still retaining its heat of compression—is delivered directly by each stroke of the compressor alternately to the top and bottom of the hammer piston. This arrangement has the advantage of 20 to 40 per cent better efficiency than that in which the compressor is a separate machine, and as no piping is necessary the complete unit may be fixed very readily in any convenient position, in the centre of the shop, or under a crane, without much interference with other plant. For smaller hammers up to 1 or 2 tons this type of unit may be most effective and efficient, but where larger hammers (of 5 tons and over) are necessary, it may be more desirable and less costly to install separate compressors and to take advantage of the diversity factor normally operative in forge experience and which is dependent upon the fact that the hammers are not usually working all at the same time, but that each has waiting periods between "heats." Where, for instance, three hammers are in use the total power available may be reduced by 30 per cent if they are supplied from a common air service.

The cleanliness and convenience of a forge arranged on these lines, as compared with the typical steam-operated conditions, need not be described; the cost of power per ton of material forged is determined very accurately and is consistent; and it can be shown that, after allowance has been made for the labour and losses incidental to steam generation and transmission, there is little or no advantage in the latter unless steam is required for other purposes.

ELECTRICAL RE-HEATING FURNACES

To complete the total electrification of the forge and mill it will be necessary eventually to substitute large electrical re-heating furnaces in place of the coal- or gas-fired types at present in use. There are various reasons for the apparent delay which has occurred in the general application of electricity to this purpose, but the advantages are, again, self-evident, both in regard to smoke elimination, furnace efficiency, and simplicity in operation.

The efficiency of the resistance furnace is essentially very high, as there are no flues to convey the heat away, and nearly all that developed can be retained by suitable heat insulation incorporated in the furnace lining. To maintain uniform heating along the furnace chamber is not a difficult matter, and by thermostatic or pyrometric control it is possible to maintain continuous and close accuracy in temperature without much attention or labour expense for operation.

As already mentioned in connection with the heating of certain classes of steel, it would be difficult to imagine any type which would be better adapted to fulfil the required conditions. The furnace chamber may be sealed, or provided with the reducing atmosphere necessary to prevent excessive scaling or decarburization, and, since access for coal supplies or ash removal is not necessary, and no gas or water service need be considered, the furnace may be placed in the best position relative to

the hammer or rolls, and without strict adherence to the conventional layout of forge or mill.

Two of the more serious difficulties, which may have impeded progress in this direction, are (*a*) the temperatures required for re-heating steel (1 150° C. to 1 250° C.) are higher than those for which resistance furnaces have been usually designed, and (*b*) the cost of power is not yet competitive with coal- or gas-firing under equivalent working conditions. Large furnaces are in constant use for annealing and heat-treatment generally, operating at temperatures up to 1 150° C., but for values higher than this the resistance element must be either of carborundum or other similar material, and the question of mechanical strength, as well as electrical contact, becomes much more important. The temperature range of metallic elements is being gradually extended and eventually it may be possible to produce material able to meet the conditions and to work at the maximum required for re-heating.

These constructional difficulties, although they may have seriously affected the development of high-temperature heating, are not insuperable; furnaces of small and medium sizes are working at 1 350° C. in the hardening of high-speed tool steel, and the extension of capacity to include the re-heating of ingots or billets should be only a matter of time or demand.

The misconception that electrical furnaces were too expensive and that power costs were prohibitive has received attention elsewhere, but the reduction of the indirect charges for operation and repairs, in addition to the superior results obtained, are factors which must be recognized. It is almost, if not quite impossible, in the flame-heated furnace to avoid the effect on the brickwork, the expansion and contraction of the sections where flames impinge, the intense local heating, and the actual erosion at vital points. The result is that expensive repairs are frequently necessary, and production must be interrupted until they are completed. It may be advisable to note the difference in the conditions which exist in the resistance furnace. The flameless nature of the heat simplifies maintenance, and, as the temperature of the elements is approximately equal to that acquired by the steel and the whole of the space is uniformly heated, there are no undue stresses to affect the life of the brickwork lining.

ELECTRICAL HEAT-TREATMENT

At the lower range of temperatures (below 950° C.) the resistance furnace has already become well established; there are many operations in the heat-treatment department, for instance, involving the hardening, tempering, or annealing, of material in the form of bars, or as machined and finished parts, where the constant temperature and the uniformity of heating are supremely important in attaining equality of effect throughout the body of the steel. Unlike the conditions in a flame-heated furnace, there is not a wide difference in temperature between the elements and the material; the result is an even absorption of heat by the steel, and local heating, which would produce distortion of the work, is avoided. Distortion is usually expensive as subsequent machining may be necessary; it has been shown also that, metallurgically, the material is superior if final grinding or machining after treatment can be dispensed with, and the tendency to scale is considerably reduced owing to the non-oxidizing atmosphere which exists in the furnace chamber.

BRIGHT-ANNEALING

One of the quite recent applications, at least in this district, and probably one of the most successful, is the use of resistance-type furnaces for the bright-annealing of steel wire and strip. By interchangeable annealing pots, each of which is fitted with an automatic valve to seal off the atmosphere under given conditions, it is possible to arrange for a comparatively large output of material from a single furnace. The space occupied and the labour required are reduced to a remarkable degree, whilst the power consumption can be less than 160 kWh per ton of material treated. This compares very favourably with the cost of fuel in other systems of bright-annealing, but the economy of time and the cleanliness of the electrical method are not in any sense comparable.

There is, apparently, a very wide field open to this and similar processes, where it is possible to revolutionize existing arrangements, or to remove them completely and replace them with more modern ones. To those who are familiar with the usual annealing plant—the large stationary or revolving furnaces, gas-producers, or coal fires with their smoke and fumes, the trucks and rails for coal and ash transport, and the general atmosphere of dirt and grime—the clean, orderly, and compact arrangement of the new method is a revelation of what can be accomplished in this section of steelworks practice. It promises to be quite as effective and popular as the high-frequency furnace has proved to be in the melting department, and further developments may be anticipated as experience with the system becomes more general.

STEEL-MELTING

The melting of steel by electrical methods has been confined, so far, to those grades which justify, by the high quality demanded and their market price, that extra carefulness in production which is afforded by the electrical furnace.

Sufficient time has elapsed since the introduction of the high-frequency or coreless induction process into the steel foundry to arrive at some idea of its usefulness, and to estimate not only its value when compared with crucible steel melting but its relative position with regard to the production of steel in the arc furnace. The reduction of working costs in comparison with coke-fired crucible practice has been claimed as one of the chief advantages in favour of the high-frequency method, and there has been confirmation of this during some years of experience; but there are several other reasons also to account for the rapid extension of the new process of steel melting, amongst which may be mentioned the fact that the production of a wide range of high grade, and special alloy steels, including extra-low-carbon stainless iron, can be made a simple procedure which is strictly under control and is capable of yielding very accurate and consistent results. It is cleaner, and more convenient, than any other existing method, particularly for small quantities of material, and, in spite of the somewhat heavy capital expense necessary for the installation of high-frequency plant, it has to a large extent superseded the use of the crucible.

It is agreed that most steels which were formerly made only in the crucible can now be produced with equal or greater success in the induction furnace. There are certain exceptions, however, namely a few types of steel for which the crucible process is still definitely preferred in some works; and the continuance of coke-firing on a limited scale may be expected until the steelmaker is satisfied that with these grades also it is possible to obtain in the induction furnace a similar high standard of quality.

Recent progress in high-frequency melting has evolved, as one would anticipate, a larger type of scheme and an increase in the capacity of the furnace itself, 4 and 5 tons per heat being quite normal in local works, whilst still larger units have been installed abroad; but the smaller sizes, which in operation approach more closely to orthodox crucible conditions, are invaluable for small batches of material, and it is usual, therefore, to arrange for two or more furnaces, of different capacities, to work alternately from the same electrical equipment in order to meet the varying demands of the melting programme.

The design of the furnace and the electrical gear generally is being modified in accordance with experience; the construction of the furnace coil and box has been altered considerably since the introduction of the earlier examples, and automatic or semi-automatic control is now provided not only for normal-voltage adjustment and variation for condenser switching, but for full correction of reactive kVA when desired.

During the early stages of development various problems have arisen, both in design and operation, and, following the experience gained under actual working conditions, the high-frequency process has been made much more serviceable and is now, with the arc furnace, an essential part of the modern steel foundry. The efforts of the steelmaker and refractory expert have been successful in eliminating, almost completely, the difficulties which occurred in connection with furnace linings, so that, given a suitable construction of the framework and the necessary care in the selection and grading of the refractory, it should be possible to ensure a continuous and prolonged life from each lining of either acid or basic material.

There appears to be fairly conclusive evidence that, for metallurgical reasons, frequencies of approximately 2 000 cycles per sec. are preferable in furnaces of 5 or 6 cwt. capacity, whilst perhaps half this value may be satisfactory for sizes of 1 ton or over. It has been necessary also to realize the significance of various critical factors which become more important at these frequencies, and to consider their effect upon coil design, conductor spacing, and other details in the arrangement of the plant.

The use of the induction furnace for refining purposes after melting has not yet reached the stage where it can affect the position of the arc process. The two types remain to some extent complementary, each having its own special advantages; the efficiencies and the consumption in units per ton of finished material for either process are about equivalent under similar conditions of operation, but where large outputs per melt are required, with subsequent refining of the steel, only the arc furnace need be considered, and there is apparently no reason to anticipate that the high-frequency method will be substituted unless, or until, the situation is altered by future developments.

The general outline of the later designs in arc-furnace construction do not differ very greatly from those with which we are already quite familiar, except that, in some cases, the principle of water-cooling has been extended in order to protect certain exposed sections, and efforts have been made, by relieving the heavier stresses, to limit the distortion of the body or framework. There has been a tendency to increase the voltage on the electrodes, and the automatic adjustment of the current in the arc and the control of the furnace have been much improved by modifications in the current regulators and other apparatus. Later arrangements include a quick-return motion on the electrode motors, and this, together with a higher degree of sensitivity in the control gear, gives a more prompt response to furnace conditions. The adjustment of current in the arc can be made entirely automatic once the gear has been set to the predetermined value, and from the commencement of operations the regulators are able to take full control and retain it throughout the complete cycle of melting and refining. The time occupied, therefore, particularly the melting period, may be reduced and a saving may also be effected in power consumption.

The progress in arc-furnace practice and design in recent years has been kept in line with that in other sections of electrical equipment, so that the foundry, which forms the basis of steelworks activities, is well adapted by electrical power to produce efficiently and consistently whatever class of steel modern conditions may demand.

OTHER APPLICATIONS

It may appear that more than sufficient space has been already devoted to the consideration of electro-thermal processes. The subject is a very wide one and it has been possible only briefly to examine a few of the more important features; many other operations for which electrical furnaces have become essential have, of necessity, been excluded from the present review. It would be tedious and unnecessary to attempt to enumerate most of the applications for which electrical power is now deemed to be indispensable. The research and chemical laboratories, for instance, are employing electrical methods for heating, testing, and other purposes, to an extent which could be described only in a separate paper of considerable length, and the whole subject of electrical driving, the progress in design of motors, control gear, etc., as applied to steelworks, has also been omitted. In these sections there would, very probably, be material of a more interesting nature, but the intention has been to indicate some of the advantages which may be expected when electrification becomes general and complete; advantages in the form of facilities for the production of better steels, and methods which would solve the problem of smoke clearance.

Even from our present vantage point we may seem to be looking well ahead when we imagine steelworks devoid of smoke, and free from most of the dirt and grime now accepted as ordinary conditions attached to the

manufacture of steel; possibly we have little, or no, conception of the transformation which could be made not only in the works but by a general attack on atmospheric pollution outside. The situation calls for action on a wider basis to deal with the latter problem. During the Conference of the National Smoke Abatement Society held at Bristol a few weeks ago it was stated that nearly $2\frac{1}{2}$ million tons of soot escape annually into the air of this country, and that the yearly loss sustained by the community was probably equal to £1 per head of the urban population. It was agreed that after slum clearance must come smoke prohibition.

Electricity has already accomplished much in this matter and there may be a more definite and predominant part to play in reaching the desired result; how speedily the change may come will be very largely dependent upon the supply engineers and their ability to reduce the cost of power still further, to a really competitive level. In the steelworks such a conversion would be welcomed and there would be no hesitation in their acceptance of complete electrification, in view of the success already achieved by the electrical engineer. This is the only tribute he is entitled to expect—to be entrusted with more difficult tasks, or, as George Eliot has expressed it in a more simple and a more impressive phrase, "the reward of one duty is the power to fulfil another."

TEES-SIDE SUB-CENTRE: CHAIRMAN'S ADDRESS

By D. B. HOGG, Associate Member.

"A REVIEW OF SOME OF THE FACTORS AFFECTING THE CHOICE OF ALTERNATING-CURRENT MOTORS FOR INDUSTRIAL APPLICATIONS"

(*Address delivered at* MIDDLESBROUGH, 21*st October*, 1935.)

INTRODUCTION

It is customary for the Chairman's Address to bear on some aspect of his daily work, and this must serve as sufficient excuse for asking you to listen this evening to some notes on polyphase a.c. motors.

It is many years now since a.c. motors came into common use, and they are such familiar objects to many of us that there is considerable danger of our falling into the proverbial state of contempt.

Therefore, a brief review of the capabilities of the more usual types and their suitability for driving normal industrial machines may not be out of place.

It must be stated that any opinions expressed in these notes are personal and are not necessarily held by my colleagues or employers.

GENERAL STATEMENT OF THE PROBLEM

The problem of choosing the motor best suited to drive any particular machine is more complicated than might appear at first sight. In addition to such physical data as brake-horsepower, speed, conditions of site, and the like, there are considerations of policy, cost, standardization, and custom, to be taken into account, the whole forming an essay in economics.

While most people will agree that the best is that which, taking everything into consideration, is the cheapest in the long run, there are marked differences of opinion as to the relative importance of some of the items.

It is not my intention to discuss the cost aspect at length, but rather to take advantage of the customary, but illogical, division, and deal with the technical side only.

However, there is one point that should be made. In very many cost estimates the maintenances charges, and losses due to "outage," are either underestimated, assumed to be similar for all types of motor, or ignored altogether. This leads to one of two things, either a tendency to buy, on lowest first cost, motors incapable of fulfilling all the needs of the driven machine, or a leaning in the opposite direction to unnecessarily complicated and delicate types because of some real or fancied superiority in purely technical achievement.

The engineer must bear in mind that maintenance and outage costs are likely to swamp all other items, and only by choosing the simplest and least complicated apparatus adequate for the job in hand can he be sure of the correct solution.

SCOPE OF THE ADDRESS

These notes are an attempt to give a brief outline of seven of the factors which must be considered when choosing the motor best suited for any particular duty.

While comparisons are made between induction motors with either wound or squirrel-cage rotors and the a.c. commutator motor only, the discussion of the first three factors includes elementary matter of application to motors in general.

The seven factors under consideration affecting the type of motor are:—

(1) Brake horsepower required.
(2) Supply voltages available.
(3) Enclosure of the motor to meet local conditions.
(4) Speed and method of coupling.
(5) Starting torque required and available.
(6) Possible methods of starting, and their effect on the current rush and the supply system.
(7) Effect of transient currents.

BRAKE HORSEPOWER REQUIRED

It is, of course, obvious that the magnitude of the brake or shaft horsepower is fixed by the needs of the driven machine.

Induction motors have been made for very large powers, and the limit is being pushed higher. Units of several thousand horsepower are in use, and it is probably the effect of fault currents on the network rather than mere physical size which will call a halt.

The a.c. commutator motor, on the other hand, cannot easily be built in large units. The maximum size of which I have any knowledge is 350 b.h.p.

It is not always easy to estimate with accuracy the horsepower required by even well-known types of machines. The natural tendency to provide a motor on the big side leads to extra cost and low aggregate power factor. Fortunately, makers seem to realize this and place the optimum efficiency and power factor at about three-quarters of full output. When, in spite of this, it is known that many factories have a power factor of the order of 0·7 one is led to suspect a deep-seated misapprehension regarding the capabilities of the modern motor to start up the average machine.

SUPPLY VOLTAGES AVAILABLE

Except in large factories there is little or no choice, the matter being settled by the supply undertaking concerned. Sometimes both high and medium voltages

are available. High-voltage motors cost more than medium-voltage ones, but savings in switchgear, transformers, and cables, usually more than offset this. The practical lower limiting sizes are 300 b.h.p. for 6·6 kV and 1 000 b.h.p. for 11 kV; below these the windings are weak and mushy with far too high a ratio of insulation to active material.

Alternating-current commutator motors are not made, as far I am aware, for voltages higher than 600.

ENCLOSURE OF THE MOTOR TO SUIT LOCAL CONDITIONS

Local conditions usually influence, if they do not decide, the enclosure necessary.

Where water, dirt, and gas, either explosive or corrosive, are present they must be kept away from the windings. The most usual practice is either to pipe clean air to the motor or to enclose it totally.

Where only dust and fluff are present a filter bolted directly on to the motor is useful; alternatively it may be placed outside the building and connected by piping. One popular type consists of a frame holding one or more units, each comprising a box filled at random with metal ferrules. The box with its ferrules is dipped in a viscous oil and drained before assembly in the frame. The tortuous paths presented to the cooling air ensure that fluff and dust are deposited on the oily surfaces.

Attack by or explosions due to gas may be prevented by forced ventilation. This, however, is expensive and the piping a nuisance. In many places, of course, statutory regulations specify flame-proof motors where inflammable gas is concerned. It might be noted that the type of gas is important, as a flame-proof enclosure suitable for methane or " fire damp " is not necessarily adequate for acetylene, pentane, or hydrogen.

The simplest protection against dirt and liquor is total enclosure. This unfortunately increases the cost enormously, as only about one-third of the output is obtained from a given frame size.

For some years now, totally-enclosed motors have been fitted with radiators either air- or water-cooled. The latter are so effective that outputs are obtained equal to or even better than those from the machine when ventilated. Without special cooling plain totally-enclosed machines cannot be made for outputs over about 70 b.h.p., as it is impossible to dissipate the heat from the carcase quickly enough.

The frame-cooled or double-shell motor is becoming increasingly popular. In this machine the inner shell totally encloses the windings and is cooled by a stream of air driven by a fan on the motor shaft between the two shells. In some forms on the market special pains have been taken to increase the cooling by passing the outer air through passages in the carcase. Unless the conditions are ideally free from dust these passages are liable to choke and in any case are certain to get coated with a layer of non-conducting dust, leading to overheating and possible burn-outs.

This is another instance of maintenance and outage costs being ignored in favour of low capital prices. The simpler forms, on the other hand, are easy to clean and almost unchokable. The output and cost of a frame-cooled motor lie between those of the totally enclosed and ventilated types, inclining toward the latter in the larger sizes. Outputs over 70 b.h.p. are available, but below about 7 b.h.p. there is little or no advantage in cost.

It is sometimes proposed to enclose a ventilated motor or open a closed one to meet changed conditions. This is seldom feasible, because, although for the same frame size the outputs are as 3 to 1, the designs are fundamentally different in the way the losses are arranged. The ventilated machine is built to give the bulk of its heat to the air stream, and closing it up may cause it to get unduly warm on its light-load losses, which of course have not been altered although the duty has been reduced to one-third.

The enclosed machine is so designed that the heat formed will readily flow to the carcase to be carried away by convection currents. Ventilating this type will not permit the output to be increased *in proportion*, as the air cannot pick up the extra heat.

SPEED AND METHOD OF COUPLING

The speed requirements of the drive affect the choice of motor in two ways. They decide whether a fixed-speed or variable-speed motor is to be used and whether the speed is such that direct coupling is a practicable and economical proposition.

Variable Speeds

Where variable speeds are called for the range decides the type of motor and need for forced ventilation. The number of steps in the range decides the method of control and the practicability of using mechanical devices to achieve this end.

Mechanical means of speed variation fall into two classes, those having a number of fixed speeds, such as gear-boxes and stepped pulleys, and those infinitely variable within the range, such as hydraulic couplings, coned pulleys, and the many more or less weird infinitely-variable gear arrangements on the market. Space does not allow these to be discussed at length, but, generally speaking, they do not seem popular except for machine tools or in the smallest sizes.

Hydraulic coupling is coming into prominence, partly as a result of experience gained in some well-known makes of motor-cars. There are three types of such coupling, but only the variable-speed one interests us. Unfortunately it does not appear to be a true torque convertor, and when used below full speed much of the input to the motor is wasted as heat in a manner analogous to the resistance-controlled induction motor.

When the speed variation is to be provided by the electric motor the choice lies between the wound-rotor motor with resistance control, and the a.c. commutator motor. If the range exceeds 4 to 1 the induction motor cannot be used as it becomes unstable even on drives whose torque varies as the square of the speed. On constant-torque loads it tends to be unstable below half speed. The a.c. commutator motor is much more expensive in first cost than its rival, and in my experience is much more delicate, with higher maintenance costs.

Comparing a number of actual installations from 2·5 to 175 b.h.p., the commutator motor plus simple

circuit breaker cost exactly twice as much as the wound-rotor motor plus circuit breaker and controller.

On constant-torque drives the power input to an induction motor is approximately constant at all speeds. When the speed is below full speed, the difference between the power input and that taken by the driven machine is wasted in the control resistance. A commutator motor, however, is a constant-torque machine, and the input varies roughly as the speed.

Making due allowance for the lower capital and maintenance cost of the induction motor, it is a better proposition when the speed range can be kept within 25 per cent of full speed; below that figure the commutator motor wins. Where a good starting effort is required the induction motor is better.

Where, however, the torque requirements vary as the square of the speed (e.g. fans and centrifugal pumps) the induction motor input is not constant, and approximates fairly closely to that of the commutator machine. For such drives there is little justification for departing from the simpler machine, unless the speed range is excessive. [Curves of kilowatt input against percentage of full speed were shown at the reading of the address for each of the above cases.]

Fixed-Speed Motors

Whether to couple direct or interpose gears depends on the relative costs (capital, energy, maintenance, and breakdown) of the various combinations. High-speed motors are, of course, smaller and easier to handle than low-speed ones. Either the wound-rotor or squirrel-cage induction motor would be preferred to the commutator motor for such duties.

THE STARTING TORQUE REQUIRED AND AVAILABLE

"Starting torque" here means the effort required to break away from rest and accelerate up to full speed.

Most ordinary machines found in industry can be divided into one of six groups, according to their torque requirements.

Group 1.—Constant torque, having great inertia and stiction, started up against load.

Group 2.—Similar machines to Group 1 but started "unloaded."

Group 3.—Constant torque, with low inertia and stiction started against full load.

Group 4.—Similar machines to Group 3 but started "unloaded."

Group 5.—Machines whose torque varies as the square of the speed, arranged to reach full load at full speed.

Group 6.—Machines similar to Group 5 but started against closed delivery valves so that they only attain about 40 per cent load at speed.

Table 1 shows a number of typical machines set out in their groups.

We can now examine the characteristics of our three types of motor to determine to what extent each is suited to drive the machines in these groups.

Owing to its cost and fragility the commutator motor is only considered where the range of speed variation required puts the other two out of court. For reasonable ranges it has a starting torque of about $1\frac{1}{2}$ times full-load torque when started on its lowest speed, and it cannot be used for machines in Groups 1 and 2.

This type will be ignored for the remainder of the paper, as it is considered to be of value only where wide speed-ranges are necessary.

Comparing the starting characteristics of the wound rotor and the squirrel cage, we find we can exercise a considerably greater measure of control of the former machine during the starting period. The wound rotor, as is well known, is started and brought up to speed by cutting out gradually a variable resistance, exterior to it and connected in its rotor circuit. By choosing suitable values any torque up to about 2·75 times the full-load value can be obtained and thus any normal machine can be started.

Table 1

Group	Machine characteristics	Examples
1	Constant torque. Great inertia and stiction. Started against load	Rotary kilns; ball and rod mills; textile calenders; beetling machines; loaded belt conveyors and elevators; etc.
2	Similar to Group 1, but "unloaded" at starting	Normal flywheel compressors; unloaded conveyors; line shafting (long); unloaded ram pumps; motor-generators; etc.
3	Constant torque, low inertia and stiction, started against load	High-speed positive rotary pumps; ram pumps accumulator loaded; etc.
4	Similar to Group 3, but "unloaded" at starting	Short line shafts on loose pulleys; unloaded positive rotary pumps; machine tools; power saws; etc.
5	Torque varies as (speed)^2, reaching full load at speed	Fans; centrifugal pumps with open delivery valves
6	Torque varies as (speed)^2, started against closed delivery. Load reaches 40 per cent at speed	Fans and centrifugal pumps with closed delivery valves

By this method of starting the rate of acceleration can be controlled. As it is not unknown for fan tips to be bent and crankshafts strained by rapid acceleration during the running up period, this is a very valuable feature and compensates to some extent for the high cost and complication of the apparatus. Hand control of the starter is being replaced in many installations by some form of semi-automatic push-button-operated gear. Where this is designed to take into account the needs of both the motor and driven machine it should be an improvement on the human element.

The normal squirrel-cage machine, though far simpler,

cheaper, and more robust, has the disadvantage of an inherently poor starting effort because it is designed for minimum practicable losses and reactance.

Little or no control of the rate of acceleration is possible beyond that exerted by the driven machine. It should be remembered that for any given machine the starting torque cannot be improved by "fancy" switching. The object of the alternative starting methods used is to minimize the current rush and is always accompanied by a reduction in torque.

[At this point curves were shown comparing the torque/speed characteristics of the wound-rotor motor and the squirrel-cage machine.] It is clear from the curves that any machine can be started by a wound-rotor motor with a suitable resistance, but only those comparatively easy to start (i.e. in Groups 4, 5, and 6) by the squirrel-cage machine. Until fairly recently this automatically ruled out the squirrel-cage motor, quite apart from any other considerations, from driving the numerous machines requiring a starting effort in excess of 125 per cent of full load, but to-day there is available a choice of two other forms of squirrel cage having an increased torque at starting and one with low torque and low current-rush.

First let us consider a rotor with a single cage designed to give high initial values of torque. By making the rotor conductors, or end-rings, or both, with high resistance, the initial torque can be raised to over twice full-load value without increasing the starting current, in fact it may decrease it. This is accompanied by a fall in efficiency of 2 or 3 per cent, the power factor not being appreciably affected.

It is clear that twice full-load torque will start practically any type of machine except perhaps exceptionally "sticky" ones, and where power is cheap or the duty intermittent this type has advantages.

An alternative choice is the double-cage machine. This has two windings on the rotor, the outer having high resistance, while the inner, of low resistance, is embedded deeply in the iron. At starting, the induced rotor currents have a frequency equal to the supply, and the consequent high impedance of the inner reactive winding forces the greater part of the current into the outer, giving an excellent torque. As the machine speeds up, the impedance of the inner winding falls until at the working speed practically all the current is carried by the low-impedance cage, giving a high efficiency and only a slight reduction in power factor. A certain amount of control of the characteristics of these machines is possible in the design stage to meet varying requirements. [Torque/speed curves of three designs were shown at the meeting, one for a typical machine with a running efficiency comparable with the standard type and torque increased at starting from 125 per cent to almost 175 per cent, and two for machines with greater starting efforts and only slightly lower efficiencies, the decline being 0·6 and 1 per cent respectively, while the power factor had declined by 3 and 7 per cent.] Machines of the third type have been used to drive belts carrying material to "piece workers." Their natural tendency to overload the belt to increase their earnings at the risk of burning out the motor is prevented by the belt slowing down on overload. The advantages in using the double cage in preference to the high-resistance rotor where the starting torque allows, lie in the higher efficiency and lower starting current. For the cases shown the currents are 4 times, 4·75 times, and 3·45 times full load compared with 5·8 times for the high-resistance and 6·3 times for the standard rotors.

From the foregoing it is clear that, considered from the angle of starting effort alone, the squirrel-cage motor can be made the equal of the wound rotor, and capable of driving almost any constant-speed machine.

For the driving of machines in Groups 5 and 6 the standard squirrel-cage motor, started direct, possesses ample torque for starting purposes, and in fact, as has previously been mentioned, the high peak of torque that occurs just before full speed is reached may prove detrimental as tending to damage the driven machinery, e.g. the tips of fan blades. Also, the heavy current demanded by a standard squirrel-cage motor when started direct is an unnecessary imposition on the supply system where the torque required on the driven machine is only low. The double-squirrel-cage motor may be built to avoid the high peak of torque mentioned above, and also the starting current will be appreciably lower than for the standard single-squirrel-cage machine. The average starting torque, however, is usually a great deal more than is necessary comfortably to start machines in Groups 5 and 6. An intermediate class of rotor winding exists, employing a single squirrel cage of "deep" bar, "L" bar, or other type, which provides a motor that demands a relatively low starting current when switched direct on to the line, while still giving sufficient starting torque to deal with machinery of Groups 5 and 6.

Such machines have, as a rule, a maximum torque capacity somewhat lower than that of the standard squirrel-cage machine, and in this connection it should be remembered that these motors show a greater liability to stall on either severe overloads or reduction in supply pressure.

Where the use of such motors is contemplated for the direct starting of boiler feed-pumps on important installations it is worth while considering whether the disadvantage of the low pull-out torque on sudden voltage-drops is not more important to a power plant than the lower current-rush.

POSSIBLE METHODS OF STARTING, AND THEIR EFFECT ON THE CURRENT-RUSH AND THE SUPPLY SYSTEM

The various manual and semi-automatic methods of starting wound-rotor motors are too well-known to require any description. We have seen that we can control the rate of acceleration by judicious use of the starting resistance, but the starting effort *and therefore the value of the current-rush* is decided by the driven machine.

Here it should be made clear that by "current-rush at starting" is meant the steady value of current which would persist if the speed or other conditions did not change; the term does not include the transient currents or surges which flow at the moment of closing the switch. These transients are dealt with later in these notes.

Returning to the current-rush when starting wound rotors, it will be found that its value depends on the torque taken at starting. Using the test figures of a

typical motor it was found that if the drive required twice full-load torque at starting, the current was about twice full load, and to obtain the maximum torque a current of $3\frac{1}{2}$ times full load was needed. With squirrel-cage motors the magnitude of the current-rush at starting is fixed by the design, and is independent of the torque required or starting method except where this alters either the connections or the applied voltage. The duration of the starting current is mainly a function of the inertia of the driven machine.

Every device used to lessen the magnitude of current-rush of a given machine must also lower the starting effort. It is clear, therefore, that the squirrel-cage motor will give the best starting effort when switched directly on to the supply. Under these conditions a high-efficiency machine with "normal" rotor will take from 6 to 10 times full-load current and will break away from rest the machines in Groups 4, 5, and 6.

To reduce this current the commonest devices are the star-delta and the auto-transformer starters. The former can only be used with machines designed to run normally delta-connected, and this may impose restrictions on the designer. In the starting position with the windings connected in star the voltage across each phase is $\sqrt{3}$ times the line voltage, the current-rush in the line is reduced by 66 per cent from 6·3 to 2·1 times full-load current, and the starting torque in the same proportion from $1\frac{1}{4}$ to 0·42 times full-load torque. This low starting torque is still sufficient to get away fans, pumps, and motors, started light.

When the machine is nearly up to speed the starter is changed to the running position, connecting the windings in delta across the line. The current-rush on changing over depends on the type of driven machine, and varies from about full load for easy starts to 3 times full load for machines which attain full load at full speed.

The Auto-Transformer Starter

This device consists of a change-over switch which when in the starting position connects the motor to the line through an auto-transformer, and in the running position cuts out the transformer, making the connection direct. The motor may be designed with windings connected either delta or star.

The auto-transformer is arranged with tappings so that the impressed voltage may be any suitable fraction of the line pressure. At a tapping to give 58 per cent of line voltage it has the same effect as using a star-delta starter, tappings below or above that give corresponding variations in starting torque and current-rush. Its advantage over the star-delta starter is to give increased starting torques at the price of increased current, but it is questionable whether its greater cost and lack of reliability are worth it.

These two starting methods can, if desired, be used with any of the special rotors mentioned.

Friction Clutches

Many engineers favour the use of friction clutches. It sometimes appears that these are treated as if they are torque convertors to enable a motor to exert a greater turning effort at starting. This is, of course, not the case. Their function is to let the motor start and run up more or less unloaded until it is capable of exerting a torque of sufficient value to start the driven machine, whereupon it connects the two and transmits the required power.

There are two forms available, the free-shoe type, which slips until the speed is such that the motor is capable of exerting sufficient torque to turn its drive, and the spring-loaded type, which exerts no drag at all until at a pre-determined speed (and torque) centrifugal force overcomes the hold-off springs, the shoes suddenly fly out, and the clutch immediately transmits almost its maximum torque.

It is seldom that the additional cost and complication of these devices is justified, now that rotors with suitable characteristics are available.

Direct-on Starting—The Effect on the Supply

It has been shown that for a given machine of the squirrel-cage type the best starting effort is obtained when it is started direct on the line.

In the early days of the supply industry when power plants were small, the load mainly domestic, and carbon or arc lamps the only electric light source, supply undertakings could not tolerate violent voltage fluctuations. Therefore it was customary to refuse to allow motors over about 5 b.h.p. to be started by direct switching. To-day, however, on heavy networks where ample power is available this ban is being slowly lifted, and large machines of hundreds of horsepower are being started in this manner in the power stations of authorized undertakings. Not only is the effect not disastrous, but very often the single kick of the direct start is far less noticeable than the double one of other methods.

EFFECT OF TRANSIENT CURRENTS

Before describing some actual installations it might be well to discuss the phenomenon and effect of transient currents.

So far in these notes references to current-rush have connoted the current which would persist if the rotor remained at standstill and the voltage constant. In addition to these there occur, at the moment of switching and changing over, momentary charging or surge currents superimposed upon and additive to the steady current. These transients are frequently of considerable magnitude and their effect on the network is more marked than that of the starting current. Their exact nature and amplitude vary with the type of motor, whether wound or squirrel cage, and if the former whether the secondary is open- or short-circuited. They also vary with the state of the motor at the moment of switching, whether it is at standstill, running below or at synchronism, and lastly whether the operation is one of switching-in or of changing-over.

Some research on these matters has been done by Brown-Boveri and published in their *Review* of September, 1927. Unfortunately this article did not cover phenomena during the change-over when using a star-delta or auto-transformer starter.

From oscillograph records taken by various people at different times it is clear that when the pressure is switched off the stator of a motor the induced secondary current in the rotor takes time to die down. One record

showed traces after 2 seconds, and an amplitude greater than 20 per cent after $\frac{1}{2}$ second.

If, then, when changing over a star-delta starter the residual secondary current is in direct phase opposition to the currents which are required to flow at the instant when contact is made with the full line voltage, a resultant surge will flow which may considerably exceed that which would occur if the motor had been switched directly on to the line at standstill.

It is unfortunately impossible for me to reproduce these oscillograph records illustrating the magnitude of the surges likely to happen, but the following figures have been taken from typical tests. A certain standard squirrel-cage motor whose full-load current is 43 amperes was switched straight on to the line at full voltage. The steady starting current was 310 amperes (r.m.s.), or 7·2 times full-load current. The switching surge was lower than expected and corresponded to an r.m.s. value of 410 amperes. The motor was coupled to a centrifugal pump set to take full load at full speed, and completed its start in 0·5 sec. The same motor was started by a star-delta starter. In the start or "star" position the current taken was 100 amperes and it took 2·5 sec. to attain maximum speed when star-connected. When changed to delta-connection the current taken was over 200 amperes, but the transient reached 300 amperes.

If the current when the motor is started direct is considered deleterious to the network in practice, a motor with a special rotor could be used for this duty.

To sum up—if high torque is necessary at starting, heavy currents are inevitable, whether wound-rotor or squirrel-cage machines are used.

There is little or no advantage to be gained from using star-delta or auto-transformer starters to start squirrel-cage machines; straight switching with one or other of the special rotors provides a cheaper, simpler, and more reliable alternative. As in any case the supply must be adequate to start the largest motor in the installation there is no need for an arbitrary limit of 5 b.h.p., and on the most sensitive network any motor whose starting current does not appreciably exceed the full load of the largest machine connected could safely be started direct.

Details of some of the machines in my charge may be of interest. The largest machines are four of 450 b.h.p. each, driving turbine pumps. These have special rotors and the current-rush does not exceed four times full load. As these machines are wound for 6 600 volts they were arranged for remote starting by plant operatives, the high-voltage switches being in the substation. Tests taken on site with a high-speed sensitive recording voltmeter gave a voltage depression of 1 per cent and a time of 5 sec. to run up. As reactors are used to limit the fault current to the substation this is highly satisfactory.

The next group are three 320-b.h.p. 400-volt motors, again driving pumps. These also have special rotors and the starting current is about 1 800 amperes. A test was made recently under the following conditions: The two feeders to the pump house are about 300 yards long and are rated to carry 1 200 amperes each. The load shared by them at the time was about 740 amperes. Supplying the feeders were three 1 500-kVA transformers loaded to 2 000 kVA between them. The secondary voltage was 408 and the test was made in the pump-house. On switching-in the third pump the pressure fell 6 per cent from 404 to 380 volts, rising practically to normal after about $2\frac{1}{2}$ sec. None of the five other machines in the pump-house was affected. As the lighting was on a separate feeder from the substation it showed a very slight depression which passed almost unnoticed.

These and numerous other smaller machines with various types of rotor have now been in service for nearly a year and have fully justified the policy of using simple robust machines simply started.

For belt conveyors, high-pressure ram pumps, small mills, and the like, we use double-wound rotors and find no difficulty in starting up. The general rule is that up to 50 b.h.p. all constant-speed machines should be of the squirrel-cage type. Over that size each problem is considered on its merits, and so far as the larger ones are concerned only pumps and fans have squirrel-cage motors, as advantage can be taken of the low torque to install special machines.

CONCLUSION AND ACKNOWLEDGMENTS

In conclusion one is aware of many important omissions, especially any mention of power-factor improvement by the use of synchronous induction motors. What has been said is rather in the nature of a review of some common factors, but I am satisfied if I have in any way given a picture of modern possibilities. I should like gratefully to acknowledge my thanks to Imperial Chemical Industries, Ltd., and to various authorities, for permission to make use of certain of the information contained in this Address, and to Messrs. Sweetlove, Binns, and other friends, who helped me with the curves which were exhibited at the meeting.

WEST WALES (SWANSEA) SUB-CENTRE: CHAIRMAN'S ADDRESS

By C. GARFIELD RICHARDS, Associate Member.

"THE POWER ENGINEER'S TASK IN THE ELECTRIFICATION OF THE SOUTH WALES AREA"

(Address delivered at SWANSEA, *31st October*, 1935.)

STATISTICS OF THE AREA

If we regard Wales as divisible into three regions—North, Mid, and South—the counties of the southern region are Glamorgan, Monmouth, Carmarthen, Pembroke, and Brecon. Table 1 gives a set of published and estimated figures which are of interest to power engineers who have to consider the questions of electrical development in this area. The particulars relating to roads were given me by the various surveyors to the local government authorities, and the railway figures, so far as they relate to the Great Western Railway system, by the chief engineer. Apart from the fact that these five counties seem to form the natural South Wales area, any survey of the principal industries would need to cover them, because, while these industries are in the main carried on in the counties of Glamorgan, Monmouth, and Carmarthen, to a less extent they are found in Brecon and Pembroke.

Table 1

(1)	Area (acres)		2 320 781
(2)	Population		1 950 000
(3)	Public buildings, business houses, and dwelling houses		440 000
(4)	Harbours		15
(5)	Railways (route miles)		1 200
(6)	Classified roads (route miles)		1 600·65
(7)	Factories, workshops, and warehouses		9 700
(8)	Mines and quarries		460
(9)	Population per square mile		550
(10)	Population of Glamorganshire per square mile		1 500
(11)	Population of Breconshire per square mile		79
(12)	Units of electrical energy sold in 1932–33 (millions):—		
	(a) Lighting, heating, and cooking	73·576	
	(b) Power	166·586	
	(c) Public lighting	7·700	
	(d) Traction	17·636	
	Total, excluding bulk supplies to authorized undertakers	265·498	
(13)	Number of authorized undertakers		46
(14)	Approximate number of electricity consumers		236 000

Table 2 gives the figures for 1923 for electrical energy only, and enables the progress in the decade 1923–33 to be observed as far as supplies by authorized undertakers are concerned.

Table 2

		millions.
(1)	Units of electrical energy sold in 1923:—	
	(a) Lighting, heating, and cooking	15·810
	(b) Power	76·904
	(c) Public lighting	2·490
	(d) Traction	18·042
	Total, excluding bulk supplies to authorized undertakers	113·246
(2)	Number of authorized undertakings	19

RAILWAY ELECTRIFICATION

In South Wales there is much scope for the work of the power engineer, of a character which would be of immense benefit to such a depressed area. It is very questionable whether a proposal for electrification throughout South Wales to the fullest extent to which such a policy is economically sound and practicable would meet with the approval of the most important of our staple industries—coal production. From a careful consideration of the question I am of the opinion that if a long view is taken of the subject this industry is ultimately likely to gain rather than lose from such a policy. At first sight, of course, this statement would appear to be incorrect. When this question is first considered we are reminded of the Weir Committee's report of 1931, on main-line railway electrification, extracts from the estimates of which show that if the main lines of Great Britain were electrified the effect on the national coal consumption would be a reduction for railway transport from 13 400 000 tons per annum to 3 650 000 tons per annum, i.e. from 5·2 to 3·8 per cent of the national output. By what quantities have possible coal sales to the railways already diminished as the result of competition from oil-engine-driven road transport vehicles? In this reduction, together with the progressive increase of road transport and the experiments with Diesel-engine-driven trains, there are definite signs that unless the railways are electrified the loss of output to the coal trade will soon be far greater than that given in the Weir Committee's report for the probable reduction due to railway electrification. It is not possible for me to present statistics in proof of this statement, but there are abundant evidences of its soundness.

In the very heart of the coalfields, with all the poverty which the decline in the coal output has caused, it is

indeed sad to find that the bulk of the passenger traffic has now passed passed to the roads, to the profit of coal's rival—oil. Not only has the ordinary passenger traffic in the colliery towns and villages been captured very largely by the buses, but the miners themselves are being conveyed to their places of employment—even for very short distances—by oil-driven buses, and the miners' wives and womenfolk in their homes are freely using oil stoves for heating sitting-rooms and bedrooms in cases of sickness, and in some cases even for cooking in the summer season. Responsible local authorities have themselves abandoned, and have also allowed other undertakers to abandon, electric tramways in favour of petrol-engine and Diesel-engine buses, without making an exhaustive inquiry into the possibilities of change-over to trolley-buses.

Although separate consideration has not been given to the special conditions in our area for railway electrification, the physical features of our countryside would justify such a policy. The conveyance of the bulk of our export coal along tracks which gravitate towards the ports, the transport of the comparatively small tonnage of merchandise in the opposite direction, and the passenger traffic necessary in connection with this work and the lives of the people concerned, would on the face of it make the subject well worth investigation, particularly for a part of the country which still has a wealth of valuable steam coal beneath its mountains.

POWER AND ELECTRICITY SUPPLIES FOR SMALL WORKS AND ESTATES

In spite of the national policy of cheap and abundant supplies of electricity, small manufacturers, business houses, entertainment houses, and country estates, have consistently during the past 25 years been changing over from steam engines, gas engines, and water-power engines, to Diesel and kerosene engines for power purposes and the generation of electricity. During the same period new establishments in search of cheap power have readily installed Diesel engines as a result of advice and advertisements to the effect that this policy would give them the best results. Ten years ago I felt myself compelled, after a most exhaustive examination in the light of local circumstances, to advise the installation of Diesel oil engines for the generation of electricity, almost on the top of some of the finest steam-coal measures in the world. With a sense of responsibility to the community in which I live I have taken every opportunity to advise a course which would ensure that the use of Diesel engines would be confined within the limits of the original intention, i.e. as a temporary measure for surmounting a local difficulty, in the absence of a comprehensive policy in line with the requirements of the town and district. Commercial experience readily teaches us that pious sentiments are of no use in dealing with these problems.

ELECTRIFICATION OF THE METAL INDUSTRIES

Experience of mechanical engineering in industry satisfies us that, given electrical energy for power purposes at tariffs which the principal large statutory undertakings in South Wales are able to offer their users, electricity has no rival for driving stationary machinery. Mechanical engineers when considering proposals for new plant no longer regard reciprocating steam engines as serious competitors for driving stationary machinery, though new steam engines are still being built for this purpose; but the virtues of the Diesel engine are frequently considered when fuel costs, which loom so large in the power costs for heavy machinery, are under review. Notwithstanding this fact, in some of our important industries in this area the saving in operating and maintenance costs alone would be very important factors in favour of electric drive in place of obsolete steam engines and in preference to Diesel engines, and these costs should be given close consideration before a decision is taken.

There appear to be no statistical publications showing the total amount of stationary machinery in the South Wales industries which is at present driven by reciprocating steam engines and oil engines, in terms of the numbers and total brake-horsepower of these engines. In this connection I look forward with interest to the publication of the returns which the Electricity Commissioners requested authorized undertakers to make for the year ended 31st December, 1934, regarding the prospective electrical demands for industrial purposes in their respective areas. From an examination of information available it appears that, in the metal industries of the district alone, there are still in operation some 250 reciprocating steam engines varying in size from 100 to 10 000 h.p. driving stationary machinery, principally for rolling-mill purposes, and exceeding a total of 160 000 b.h.p. in all. In the mining industries the figures are of course very much greater.

In the tinplate industry there is apparently a reluctance to settle down to definite proposals for complete electrification of rolling-mill and auxiliary plant, on account of the possibility of the introduction of radical changes in the process of manufacture. Here I refer to the possibility of (*a*) the development of electroforming of thin-gauge sheets and bimetal sheets on a commercial scale, (*b*) the process of continuous strip rolling, (*c*) the transfer of the rolling of sheets up to the stage of singles to the steelworks' mills, and (*d*) the mechanization of existing sheet and tinplate mill plant. As, however, there appears to be no likelihood at present of (*a*) being able to produce sheets at competitive prices, and (*b*), (*c*), and (*d*) mean total reconstruction at high capital expenditure, it would appear to be advisable for the manufacturers and supply authorities and their engineers in the area to co-operate with the view of trying to obtain the whole of the valuable conversion to electric drive and power load of the present steel, tinplate, and sheet mills. For any new mills to be constructed for either of the new processes, or for reconstructions involving new boiler and engine plant, the all-electric drive will undoubtedly be chosen. Electrical engineers should now endeavour to put forward acceptable proposals for agitating the sulphuric-acid pickling tanks in the sheet and tinplate industries. In the case of existing plant where the steam engines are giving satisfactory service, power prices have definitely to be cut to the finest limits to present a case which will justify the capital expenditure of a change-over to electrical drive. If electrification of existing plants is to take

place in districts where the authorized undertakers are compelled to commence by taking their bulk supply at grid-tariff terms, in order to get down to the power rate necessary, the combination of the industrial power load with the fullest development of the domestic load is positively essential. Only the diversity of these loads will enable authorized undertakers to quote competitive prices for complete conversion, unless the conditions of the steam plant necessitate reconstruction. The question of the electric drive of existing rolling mills is a matter upon which statutory supply authorities, electrical manufacturers, and metal manufacturers, should try to co-operate for their mutual benefit, because rolling-mill experts are satisfied that the electric motor gives unrivalled technical advantages.

ELECTRIFICATION IN THE MINING INDUSTRY

In the mining industry generally the mineowners are favourably disposed to a progressive policy of complete electrification, though among some engineers there are still technical objections to electric drive for winding engines for pit shafts, for certain classes of haulage, and also for coal-cutters, but one of the biggest factors retarding the change-over from steam to electricity at coal mines appears to be the continuous shrinkage in the demand for coal in the South Wales coalfield since 1923. Under these circumstances, mineowners are unable to face capital expenditure for plant conversion except where there is a positive proof of satisfactory reductions in working costs as a result. During the period 1923–33 the output of the South Wales coalfield has declined from 54 251 587 tons to 34 354 884 tons per annum.

A part of the country such as ours which is mainly engaged in the production of the best steam coal in the world should lead the way in demonstrating its most economical uses in forms which are most acceptable to the public.

PUBLIC STREET LIGHTING

For the road motor vehicles employed for the transport of agricultural produce and tourist traffic, the completion of the electric lighting of the Class 1 roads of the 1 600 miles of classified roads in the five counties is a matter which those interested in the country should now consider on a definite plan extending over a period of years.

DOMESTIC ELECTRIFICATION

It appears that our countryside lacks proper planning and the vigorous pursuit of definite policies to restore its former industrial prestige. There is some evidence of this in the fact that such little development has taken place in coal distillation in the Monmouthshire and South Crop coalfields.

In the sphere of domestic electrification, however, the statutory authorities and their electrical engineers can speed up the rate of development; but to this policy there is no mean opposition from those in authority who assume that our rival the gas industry is more profitable to a coal-producing district than the electricity industry is at present or is likely to be in the future. National statistics indicate that the real position is the reverse of this. In the year 1932–33, authorized electricity undertakers of Great Britain generated 12 380 million units of electricity, of which 0·6 per cent was generated by oil, whereas it appears that in the gas industry about $7\frac{1}{2}$ per cent of the output was due to oil.

Those who have lived in an "all-electric" house, or an "all-electric—one-coal-fire" house, know that it gives such a measure of relief from the worst of domestic drudgery, and such a standard of ease, cleanliness, and convenience—and now of good entertainment and up-to-date information—that, once having enjoyed its privileges, it would be a tremendous sacrifice to such people to be removed to an area where an electricity supply is not yet available. So satisfied are we of the new conditions which electricity creates that we are convinced that with the supply universally available the rate of progress will only be limited by the capital resources and the spending power of the people.

Of the houses in the five South Wales counties already wired, comparatively few are equipped as all-electric, or all-electric—one-coal-fire, houses. It is, I am convinced, from an examination of costs and other factors, to the latter type that our efforts had best be devoted.

From Table 1 we observe that the units sold per annum per head of population in the area in 1932–33, for lighting, heating, and cooking, are 37·7, and per separate dwelling 165. Electrification throughout the area on the plan of all-electric—one-coal-fire houses would, I estimate, show an annual consumption varying between 2 000 and 4 000 units per annum per separate dwelling, according to the circumstances. The attainment of this result would increase the consumption of electrical energy for lighting, heating, and cooking, in the area to 1 320 million units per annum, i.e. 18 times the present consumption for domestic purposes alone. At the rate of progress obtaining in the decade 1923–33 it will take nearly 40 years to achieve this increase, disregarding the prospects of a progressive increase in the number of built-up properties. From the period of the commencement of public supplies in the area it will, at this rate, take well over 83 years to attain quite a nominal standard of domestic electrification, surely quite unsatisfactory for an industry which has so much to offer.

By the optimist it may be postulated that now that supplies to domestic consumers have been established in all the towns and villages of South Wales except a very few sparsely populated rural districts, it will be a very much easier task to convert the householder to the all-electric—one-coal-fire house. To this type of mind one has to point out that the rate of growth during the period 1923–33 was favoured by the number of authorized undertakers being more than doubled, and that these new undertakings received the benefit of the sales to the business consumers in their districts, to the agitation and credit of which the advent of many of the new distribution authorities has been due. Further, the majority of these lighting and heating consumers have been able to provide their installations from their own capital resources, whereas, to reach the stage now suggested, installations and equipment greatly exceeding in cost the provision of 6 to 20 lighting points will need to be constructed in premises where but comparatively few of the consumers will have the capital required.

In my own experience the objections to the all-electric—one-coal-fire house in South Wales can be summarized in the following order of importance: (1) Capital cost of installations and equipment, and lack of ready money to meet this cost. (2) Ungrounded fears of high running costs. (3) Fear of shock, fire, and accident. (4) Apathy, and failure to realize the truly wonderful advantages offered by way of comfort and cleanliness. Let us deal with these obstacles by disposing of the easiest first, i.e. reversing the above order.

(4) Newspaper and cinema advertisements are most advantageous, especially when supported by personal canvass, and the latter can be better justified in public services like electricity than in most classes of business, because once the canvasser has secured a new consumer we have an additional customer for life. Further, he is able to satisfy the majority of consumers respecting (1), (2), and (3), in most districts on present conditions, or on those which should be in sight in the near future.

(3) Materials, apparatus, and methods of construction are available to-day which can entirely dispose of this objection. While the risk of accident is almost negligible compared with the rate of accident in all other spheres of modern life, there is still a fear of the innocent and most careful sustaining injury due to reasons beyond their own control, and this can be made practically impossible. Here I advocate strict adherence to the Tenth Edition of the I.E.E. Wiring Regulations, using metal-sheathed systems of wiring by means of vulcanized rubber-insulated cables drawn into screwed conduits, or vulcanized rubber-insulated lead-sheathed cables with mechanical protection where necessary, Home Office fittings, and 3-pin socket outlets for all portable apparatus. For a.c. systems screened sockets of the type which eliminates danger of short-circuit by children playing with pieces of metal, such as wire, are quite satisfactory, but where the consumer can and is prepared to pay for interlocking 3-pin socket-outlets and switches, or socket-outlets with scraping earth contacts, these are undoubtedly preferable. These installations can now be brought within the purchasing power of all residents in South Wales. In the case of underground services I advocate paper-insulated, lead-covered, double-steel taped, armoured cables with lead-sleeve and cast-iron joint boxes, the lead and armour being bonded at both ends of the service cable. For overhead services I favour vulcanized rubber-insulated lead-covered down-leads bonded to tinned-copper earthing tape and connected to copper earth-rods, and the bonding of the consumer's or assisted wiring installation inside as well as earthing to the water pipes. The earth connection at the service end can be readily inspected at each meter reading. The provision of earth-leakage tripping switches will then make electricity safer than any of its rivals for any domestic purposes for which these rival services can be adopted.

(2) Operating costs need no longer be an objection. The most favourable of present grid tariffs should be made available to distribution authorities in areas of reasonable sizes. Then, with the combination of the industrial and domestic loads in each area of distribution, schemes could be designed and constructed at such capital costs that, with the present rates of interest and periods of repayment allowed by the Electricity Commission, distribution costs could be reduced to the point that would make domestic tariffs generally as cheap as those now offered by very large statutory authorities: that is, a 2-part tariff with fixed charge of the order of an annual sum of £2 8s. to £3 8s. plus a running charge of $\frac{1}{2}$d. to $\frac{5}{8}$d. per unit or even less.

(1) This objection can now be met with assisted wiring and equipment schemes, the development of which for low quarterly and weekly payments can be greatly stimulated by the reduced annual charges rendered possible by the improved policy of the Electricity Commission in extending the period for repayment of assisted wiring loans from 10 to 15 years. Assisted wiring installations have other merits than those of overcoming the difficulties of capital expenditure. These installations can be carried out with a standard of engineering, materials, and workmanship, very much better than the average householder is likely to get in the competitive market, when prices are cut as a result of anxiety to get the desired amount of equipment at the lowest cost at which anyone is prepared to do the work, without regard to its quality.

In order to obtain the best results for all concerned, I would propose the development of assisted wiring installations to the fullest extent possible. Alternative classes of assisted wiring installations should be made available, ranging from, say, three lighting points and one 5-ampere 3-pin socket-outlet to 10 lighting points, one 5-ampere 3-pin socket-outlet, six 15-ampere 3-pin socket-outlets, and 1 cooker—wash-boiler—immersion-heater point. Assisted installations should also provide for the addition of heating and cooker points where lighting has been installed. Each installation where necessary should allow for a main double-pole switch-fuse and distribution board, 3-pin socket-outlets, switches for lighting points, flexibles, Home Office lampholders, cooker control change-over to wash-boiler or immersion heater, double-pole switch with semaphore indicator, and 5-ampere 3-pin socket-outlet; only lamps and shades being excluded. Apparatus, of course, will have to be hire-purchased separately.

For the purpose of comparing the annual costs to the householders of the all-electric—one-coal-fire house with the present alternative services available, the consumers who will adopt assisted installations might in this area be divided into two classes, A and B. In estimating coal costs for these householders the prices at which many of the industrial workers are able to purchase coal in $\frac{1}{2}$- or 1-ton lots through their coal clubs must be taken into consideration. If the price of coal in 1-cwt. lots, or the general retail charge even in the industrial districts of 35s. per ton, is taken, then the comparison of annual costs to the consumer will be more favourable to the all-electric—one-coal-fire house than that indicated by Tables 3 and 4 (see pages 98 and 99).

As regards the alternative services available to the all-electric—one-coal-fire house, it has been found from a careful investigation in the Port Talbot district that the householder uses from 4 to 7 tons of coal per annum, according to his income and to the amount of cooking

carried out directly on the coal fire with oven. The total annual expenditure on coals, cooking, lighting, and wireless-battery maintenance, and on matches and candles in houses without electricity, varies from £14 to £20. In most of these houses coal is burnt during the summer season and in the late spring and early autumn to the point of making the living-rooms inconveniently warm on account of the need for providing domestic hot-water, bath water, and some warmth in the early morning and late at night.

Electrical-energy charges have been calculated for Class "A" and Class "B" consumers (see Tables 3 and 4) at tariffs equivalent to the cost at which the service can now be obtained in the best statutory areas, and at tariffs with the degree of development suggested earlier in this Address they could now be made available throughout the South Wales area. In fact, a lower running charge than the figure mentioned might readily be reached a very few years hence, given a more general use of electricity in industry and in domestic premises.

Class "A" consumer will be provided with 10 lights, one 5-ampere 3-pin socket-outlet, six 15-ampere 3-pin socket-outlets, and a cooker—wash-boiler—immersion-heater circuit; and will hire-purchase a medium-size cooker, a wash-boiler, an immersion heater, and two 2-kW fires, one of which will be of good class, such as a log fire. The annual fixed charge will average £3 8s. and the average annual consumption will be 3 000 units at ½d. per unit by quarterly meter, or at ⅝d. per unit through a 2-part tariff prepayment meter (which would collect the hire-purchase charges and the fixed charge weekly, as well as the energy charge).

Class "B" consumer will be provided with 6 lights, one 5-ampere 3-pin socket-outlet, three 15-ampere 3-pin socket-outlets, and a cooker—wash-boiler—immersion-heater circuit; and will hire-purchase a small-size cooker, a wash-boiler, an immersion heater, and one 2-kW fire. The annual fixed charge will average £2 8s., and the average annual consumption will be 2 000 units at ½ per unit by quarterly meter, or at ⅝d. per unit through a 2-part tariff prepayment meter (which would collect the hire-purchase charges and the fixed charge weekly, as well as the energy charge).

With the service of an immersion-heater, electric cooker, and wash-boiler, to provide the equivalent of the present service, the householder would use on the average 3 tons of coal annually.

The proposals outlined above, if carried out in conjunction with 100 per cent electrification of stationary machinery drives, and railway electrification, would do less damage to the coal trade ultimately than the present policy of *laisser faire*, under which coal's rival—oil—is everywhere gaining ground.

For both Class "A" and Class "B" consumers the all-electric—one-coal-fire house, including the hire-purchase and maintenance of the electrical apparatus, is cheaper than the alternative service.

The assisted wiring scheme can readily be carried out through local contractors, the supply authority supervising and inspecting the installation work and financing the hire-purchase of the apparatus.

Table 3

COMPARISON OF COSTS, CLASS "A" CONSUMERS

Electrical installation and apparatus:—

	Capital expenditure	Annual capital charges at 3¼ per cent annuity	Annual maintenance cost	Annual cost to consumer
	£ s. d.	Years £ s. d.	s. d.	£ s. d.
Installation	22 10 0	15 1 18 3	2 6	2 0 9
Hire-purchase of equipment	17 0 0	7 2 14 3	7 6	3 1 9
Totals	39 10 0	4 12 6	10 0	5 2 6

	£ s. d.
Annual operating costs of present alternative to all-electric—one-coal-fire house: coal, domestic hot-water, heating, cooking, wireless-battery charging, and maintenance only (Class "A" consumer)	20 0 0
Annual capital charges of equipment considered necessary to provide Class "A" consumer with apparatus (i.e. gas lighting, gas cooker, but excluding fire-grates) for alternative to all-electric—one-coal-fire house calculated at 3¼ per cent annuity for 15 and 7 years respectively	2 8 0
Total	22 8 0
Annual costs of all-electric—one-coal-fire house:—	
3 tons of coal at £1 10s.	4 10 0
Electrical energy, fixed charge	3 8 0
3 000 units at ½d.	6 5 0
	14 3 0
Annual cost for hire-purchase and maintenance of installation and equipment	5 2 6
Total amount by quarterly meter	19 5 6
Addition for 2-part-tariff prepayment meter	1 11 3
Total annual cost by prepayment meter	20 16 9

Table 4

Comparison of Costs, Class "B" Consumers

Electrical installation and apparatus:—

	Capital expenditure			Annual capital charges at 3¼ per cent annuity				Annual maintenance cost		Annual cost to consumer		
	£	s.	d.	Years	£	s.	d.	s.	d.	£	s.	d.
Installation	12	0	0	15	1	0	4	1	6	1	1	10
Hire-purchase of equipment	11	0	0	7	1	15	4	5	0	2	0	4
Totals	23	0	0		2	15	8	6	6	3	2	2

	£	s.	d.
Annual operating costs of present alternative to all-electric—one-coal-fire house: coal, domestic hot-water, heating, cooking, wireless-battery charging, and maintenance only (Class "B" consumer)	14	0	0
Annual capital charges of equipment considered necessary to provide Class "B" consumer with apparatus (i.e. gas lighting, gas cooker, but excluding fire-grates) for alternative to all-electric—one-coal-fire house, calculated at 3¼ per cent annuity for 15 and 7 years respectively	1	15	1
Total	15	15	1
Annual costs of all-electric—one-coal-fire house:—			
3 tons of coal at £1 10s.	4	10	0
Electrical energy, fixed charge	2	8	0
2 000 units at ½d.	4	3	4
	11	1	4
Annual cost for hire purchase and maintenance of installation and equipment	3	2	2
Total annual cost by quarterly meter	14	3	6
Addition for 2-part-tariff prepayment meter	1	0	10
Total annual cost by prepayment meter	15	4	4

CONCLUSIONS

Whether or not the present organization of the industry can successfully carry through a policy of complete industrial, mining, railway, and domestic electrification, in South Wales is rather outside the scope of my Address; but it is true to say that the present method of organization of distribution has at least a few advantages. There has been a definite stimulus to development and price reductions as a result of competition with rival industries in each district, and as a result of the efforts of individual managing engineers in quite a friendly way to attain or exceed the standards of their neighbours. Further, local contacts enable the policy to be so framed as to be more closely in line with local requirements. It is, however, evident that if the industry is to reap its just reward in dealing with the speeding-up of the electrification development some efforts will have to be made to overcome the prejudices of many of those in authority. It is remarkable to find that there are still a number of responsible people who talk fervently upon the question of social improvement yet are still prepared to use their authority to delay logical developments in regard to one of the greatest improvements which can possibly take place in the domestic life of the people of this country. It is evident that it is necessary to bring some external pressure to bear upon minds of this type.

No engineer would suggest we are reaching the zenith of discovery and technical improvement, even in the most straightforward sections of the industry. It is, however, correct to state that invention and production have attained such high standards of perfection that the greatest blessing to the whole field of electrical industry can now be conferred by those who can place electricity safely in the hands of the people at prices which they can afford to pay.

We owe it to those pioneers who have given much time and thought to the development of apparatus and equipment to see that we now make contacts with those bodies who can influence opinion throughout the country in favour of our methods. We should endeavour to make contact in this area with the Industrial Development Council, so as to get railway companies, industrial organizations, local authorities, and supply undertakings to co-operate with a view to the organization of a programme of complete electrification on definite plans. If such a programme could be planned for this area it would be possible, in connection with the supply of materials and the construction of this work, to lay down such conditions as would readily lead to the establishment in this area of much-needed new industries, particularly those dealing with the manufacture of electrical apparatus. Its geographical position, natural facilities and resources, and available suitable labour, place South Wales in an unrivalled position as a site for modern metallurgical engineering and associated industries. It is impossible to imagine that those interested in this part of the country and those responsible for its government will allow such a district, so rich in natural resources, to reach a state of permanent decline and eventually become derelict.

A SEARCH-COIL METHOD OF MEASURING THE A.C. RESISTIVITY OF THE EARTH*

By JOHN COLLARD, Ph.D., Associate Member.

(*Paper first received* 21*st May, and in final form* 19*th August*, 1935.)

SUMMARY

The paper describes a method of measuring the a.c. resistivity of the earth based on the Carson–Pollaczek theory for the mutual impedance of earth-return circuits. The method consists in the measurement of the e.m.f.'s induced in a search coil placed at various distances from an earth-return circuit carrying alternating current. The experimental points are superimposed on a set of theoretical curves calculated for different values of resistivity, and the curve with which the points coincide gives the resistivity.

Where a power line exists in the neighbourhood of the site whose resistivity is to be measured, one of the zero phase-sequence harmonics can be used as the inducing current.

The method has been used to measure the resistivity of the earth at various sites in England and Italy, and the results obtained are given together with particulars of the geological formation at the sites.

INTRODUCTION

Recent developments in h.t. power lines and communication circuits have emphasized the need for a method of predicting the inductive interference which will be produced in a communication circuit when paralleled by a power circuit. The prediction of the voltage produced in the communication circuit by induction from the power-circuit currents requires a knowledge of the mutual impedance between the two circuits.

Numerous tests† have shown that the Carson–Pollaczek theory can be used satisfactorily to determine the mutual impedance between two conductors with earth return provided the specific resistance of the site is known. A means of determining the specific resistance of the earth is therefore very necessary, and the object of this paper is to describe such a method based on the Carson–Pollaczek theory.

THEORY

The Carson–Pollaczek theory results in the following expression for the mutual impedance between two parallel circuits with earth return:—

$$M = \left[-\frac{4}{k^2x^2} + 4\frac{kei'(|kx|) - jker'(|kx|)}{|kx|} \right] \times 10^{-4}$$

where M = mutual impedance, in henrys per km;
x = separation between the two lines, in cm;
$k = e^{\frac{1}{4}\pi j}\sqrt{(4\pi\sigma\omega)}$;
σ = conductivity of the earth, in c.g.s. units;
e = base of natural logarithms;
$j = \sqrt{(-1)}$;
ker' and kei' = differential coefficients of ker and kei (the Kelvin forms of Bessel functions).†

Suppose now that one of the circuits is replaced by a search coil. The e.m.f. induced in the coil is a function of the field strength at the separation. The expression for m, the mutual impedance between the coil and the circuit, is therefore the differential of the above expression for M.

We thus have

$$m = \frac{dM}{dx} = \frac{kdM}{d(kx)} = kM'$$

Hence

$$\frac{m}{k} = f(kx)$$

If, therefore, we measure the e.m.f. of the coil for different separations, different frequencies, and different resistivities, and then plot corresponding values of m/k and kx, all the points will fall on the same curve. Two values of this curve are of interest. For small values of kx the expression reduces to

$$\frac{m}{k} = \frac{2}{kx}$$

For large values of kx the expression becomes

$$\frac{m}{k} = \frac{-j8}{(kx)^3}$$

Suppose now that instead of dealing with m/k and kx we use $m/\sqrt{f}$ and $x\sqrt{f}$: then, for small values of $x\sqrt{f}$, the expression becomes

$$\frac{m}{\sqrt{f}} = \frac{2}{x\sqrt{f}}$$

Hence for small values of $x\sqrt{f}$ the value of $m/\sqrt{f}$ is independent of the resistivity.

For large values of $x\sqrt{f}$ we have

$$\frac{m}{\sqrt{f}} = \frac{1}{\sigma\pi^2} \cdot \frac{-j}{(x\sqrt{f})^3}$$

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† W. G. RADLEY and S. WHITEHEAD: "Recent Investigations on Telephone Interference," *Journal I.E.E.*, 1934, vol. 74, p. 201; J. COLLARD: "Measurement of the Mutual Impedance of Circuits with Earth Return," *ibid.*, 1932, vol. 71, p. 674.

† For Tables of these functions see Report of the British Association, 1915, p. 36.

Hence for a given value of $x\sqrt{f}$ the corresponding value of $m/\sqrt{f}$ will depend on the resistivity. We thus obtain a family of curves of which the curves for the different resistivities all coincide for small values of $x\sqrt{f}$, but differ for large values. A set of these curves is shown in Fig. 1.

Suppose that we place a search coil at different distances from an earth-return circuit carrying an alternating current. By measuring the current in the inducing circuit and the e.m.f. in the coil, the value of m can be determined. Values of $m/\sqrt{f}$ plotted on logarithmic paper against values of $x\sqrt{f}$ will give a curve having the same shape as those just discussed. If we then superimpose on the test values a set of theoretical curves of $m/\sqrt{f}$ against $x\sqrt{f}$ calculated for different values of resistivity, we shall find that one or other of the curves coincides with the test results. The resistivity for which this particular curve was calculated is then the value for the test site.

In practice it is possible to simplify the method by plotting the e.m.f. induced in the coil, instead of values of $m/\sqrt{f}$. Since the e.m.f. is proportional to $m/\sqrt{f}$, and logarithmic scales are used, the plotted values of e.m.f. will give a curve which has the same shape as the curve for $m/\sqrt{f}$ except that all the points will be displaced by a constant amount along the vertical scale. By raising or lowering the experimental points by a constant amount the points for small values of $x\sqrt{f}$ can be made to fall along that part of the curve common to all resistivities. The points for larger values of $x\sqrt{f}$ will then fall along one or other of the family of curves, and the corresponding resistivity gives, as before, the value for the test site. This method of making the experimental points fit the theoretical curve not only renders it unnecessary to plot values of $m/\sqrt{f}$ but also makes it unnecessary to know the value of the inducing current. Furthermore, it is unnecessary to know the absolute value of the induced e.m.f. provided readings can be obtained which are proportional to the e.m.f. This last fact means that the number of turns in the coil and the mean area of a turn need not be known, and rather crude measuring apparatus can be used.

APPLICATION

In the practical application of this method the inducing circuit may consist of a special test conductor laid down for the purpose, or else an existing communication conductor or power conductor may be used. The conductor is earthed at the far end and a voltage of known frequency is applied between the near end of the conductor and earth. A search coil is placed at various separations from the conductor and the e.m.f. induced in the coil is measured. A curve is plotted on logarithmic paper giving the e.m.f. against $x\sqrt{f}$, where x is the separation and f is the frequency of the test current.

A set of curves giving $m/\sqrt{f}$ as a function of $x\sqrt{f}$ are plotted on transparent paper for different values of specific resistance. These curves are superimposed on the plotted test results so that the two $x\sqrt{f}$ scales coincide. The curves are then moved vertically up and down until the test results for small values of $x\sqrt{f}$ coincide with the common part of the curves. The test values for larger values of $x\sqrt{f}$ will then be found to coincide most nearly with one or other of the curves. The resistivity corresponding to this curve is then the required value.

Since the magnitude of the inducing current does not enter into the determination of the resistivity, it is possible to effect a considerable simplification in the method when a power circuit exists at the site. There

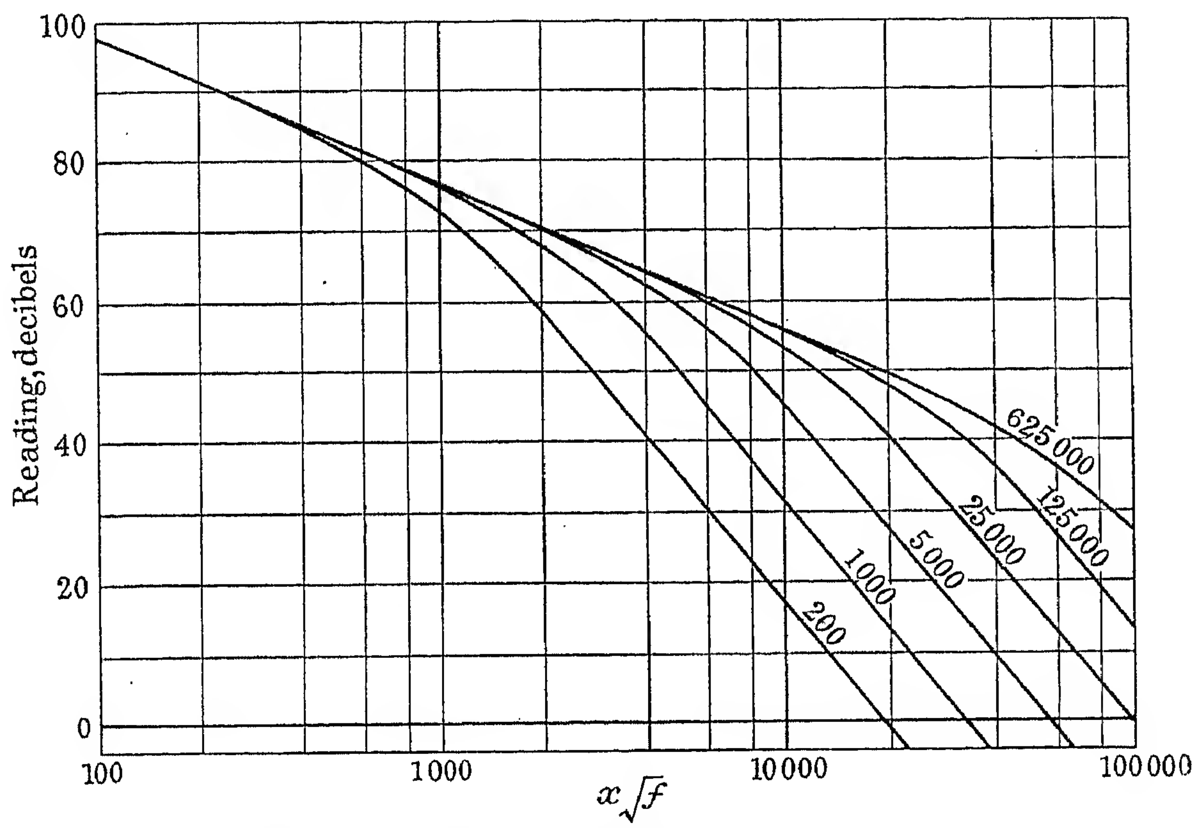

Fig. 1.—Curves for determination of earth resistivity.
(The values marked on the curves give the resistivity in ohm-cm.)

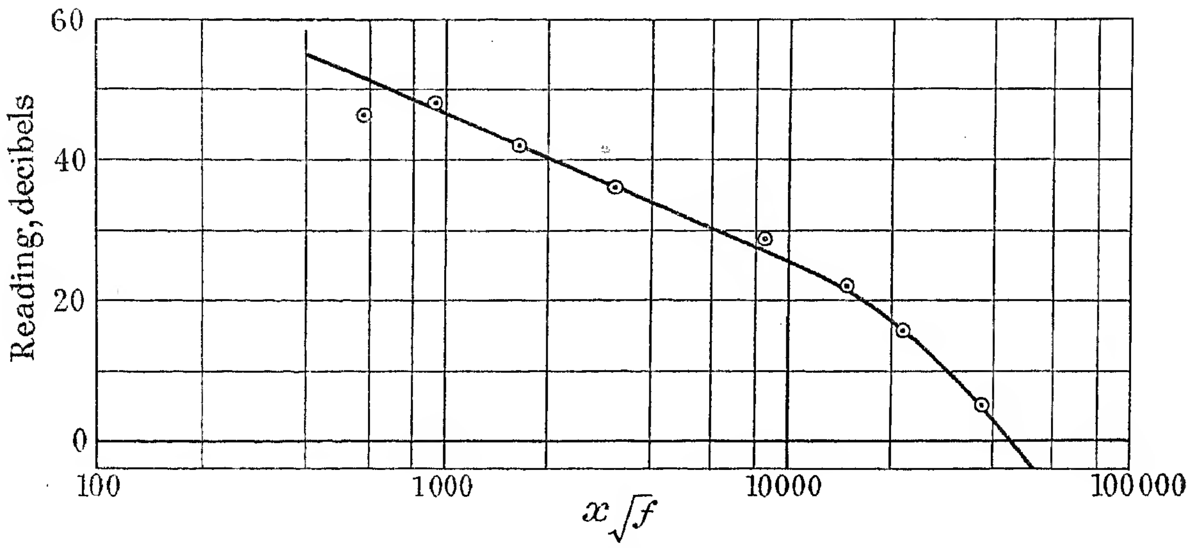

Fig. 2.—Results obtained in test on earth of resistivity 100 000 ohm-cm.

Table 1

Test No.	Date	Site	Resistivity, ohm-cm	Geological formation
(1)	16.12.31	Shenley, Herts	670	London clay
(2)	22.12.31	Eltham, London	1 500	Woolwich, Reading, and Oldhaven beds; clay, loam, sand
(3)	4.11.31	Trafford Park, Manchester	10 000	Bright red and mottled sandstones
(4)	20.12.27	Reculver, Kent	200	Alluvium
(5)	10.6.28	Goathland, Yorkshire	6 000	Inferior oolite (sandstone)
(6)	25.10.29	Weston-super-Mare, Somerset	6 000	Carboniferous limestone
(7)	2.1.32	Worthing, Sussex	4 500	Chalk
(8)	7.1.32	Eltham, London	1 000	As for Test No. 2
(9)	30.1.32	Chawston, Beds	1 000	Middle oolites, Oxford clay
(10)	3.2.32	Wheathampstead, Herts	5 000	Chalk
(11)	6.2.32	March, Cambs	400	Alluvium
(12)	9.2.32	Milford, Surrey	1 000	Lower green sand
(13)	18.10.32	Somerby, Lincs	900	Lower oolites
(14)	18.10.32	Blyth, Notts	1 000	Bright red sandstone
(15)	19.10.32	Torworth, Notts	600	Hard pebbly sandstone and conglomerates
(16)	19.10.32	Bramley, Yorks	2 000–5 000	Coal-bearing measures
(17)	20.10.32	Southwaite, Cumberland	5 000	Sandstone
(18)	20.10.32	Plumpton Wall, Cumberland	1 500	Sandstone
(19)	21.10.32	Shap Wells, Westmorland	100 000	Contemporaneous andesites
(20)	21.10.32	Shap Common, Westmorland	11 000	Wenlock group (limestone and shales)
(21)	21.10.32	Watchgate, Westmorland	25 000	Kirby Moor flags
(22)	23.10.32	Burton, Westmorland	25 000	Carboniferous limestone
(23)	10.5.33	Wood Burcote, Beds	2 000	Great oolite (shelly limestone)
(24)	11.5.33	Sharnbrook, Beds	2 000	As for Test No. 27
(25)	25.9.34	Sutton Veny, Wilts	2 000	Lower greensand
(26)	27.9.34	Stapleford, Wilts	3 000	Chalk
(27)	7.3.32	Salerno, Italy	5 000	Sandstone
(28)	8.3.32	Near Salerno, Italy	5 000	Sandstone
(29)	9.3.32	Battipaglia, Italy	450	Clay
(30)	21.3.32	Cantinelle, Italy	11 000	Upper greensand over igneous rocks
(31)	30.3.33	Bussoleno, Italy	16 000	Limestone schist
(32)	29.3.33	Turin, Italy	500	Clay

are always higher harmonics of the zero phase-sequence group which flow along the conductors of the power line in parallel and return through the earth, and any one of these can be used for this test. The magnitude of the harmonic is, of course, unknown, but this is immaterial. The frequency must, however, be determined and this can be done by introducing a resonant circuit into the measuring device. The resonant circuit is tuned to the frequency of some convenient harmonic in the power circuit, and the settings of the capacitance and inductance give the frequency. The resonant circuit also serves to separate out the wanted harmonic from any others which may be present.

The apparatus as used by the author consists of a search coil having 300 turns wound on a square frame with sides of 35 cm. This is connected to a 4-stage amplifier having a maximum gain of about 100 decibels. A resonant circuit consisting of a variable condenser and a tapped inductance in series is connected between two of the stages. At the output of the amplifier is connected a measuring device, of which two types have been used. The first type consisted of a telephone receiver which could be connected either to the output of the amplifier or to a source of complex tone in series with an attenuator. The receiver is switched alternately from one to the other, and the attenuator is adjusted until it is estimated that the loudness of the test harmonic heard when the receiver is connected to the amplifier is the same as that of the attenuated complex tone. The amount of attenuation required together with the gain of the amplifier is then a measure of the e.m.f. induced in the search coil. The advantage of this device is its sensitivity, the disadvantage being the fact that an accurate balance is not easy to obtain.

An alternative method is to connect an attenuator, rectifier, and d.c. meter, in series with the output of the amplifier. The attenuator is adjusted each time to give a standard deflection on the meter. The amount of attenuation together with the gain of the amplifier is a measure of the e.m.f. in the coil. This method is less sensitive than the former one but gives greater accuracy, and in practice it has been found sufficiently sensitive for most cases.

It will be clear from the theory that, since we are plotting the test values against $x\sqrt{f}$, the results obtained at different frequencies should all fall on the same theoretical curve. Since, however, we are plotting e.m.f. and not $m/\sqrt{f}$, and since the values of the inducing current at the different frequencies may not be the same, it follows that the results at the different frequencies may have to be raised or lowered a different amount to obtain coincidence with the theoretical curve.

The method when carried out with the apparatus used by the author does not give a high degree of accuracy. For example, if a number of sites having a resistivity of 2 000 ohm-cm were measured the results deduced from the curves would lie between about 1 500 and 3 000 ohm-cm. For other values of resistivity the same percentage error would apply. One factor tending to reduce the accuracy of the method is that, whereas the theory assumes the earth to be homogeneous, in some cases this is only approximately true. For the purpose for which these values are required, however, i.e. for calculating the voltages induced in communication circuits by neighbouring power lines, this accuracy is quite sufficient.

RESULTS OBTAINED

An example of the results obtained with this method is given in Fig. 2.

The method has been used by the author to obtain

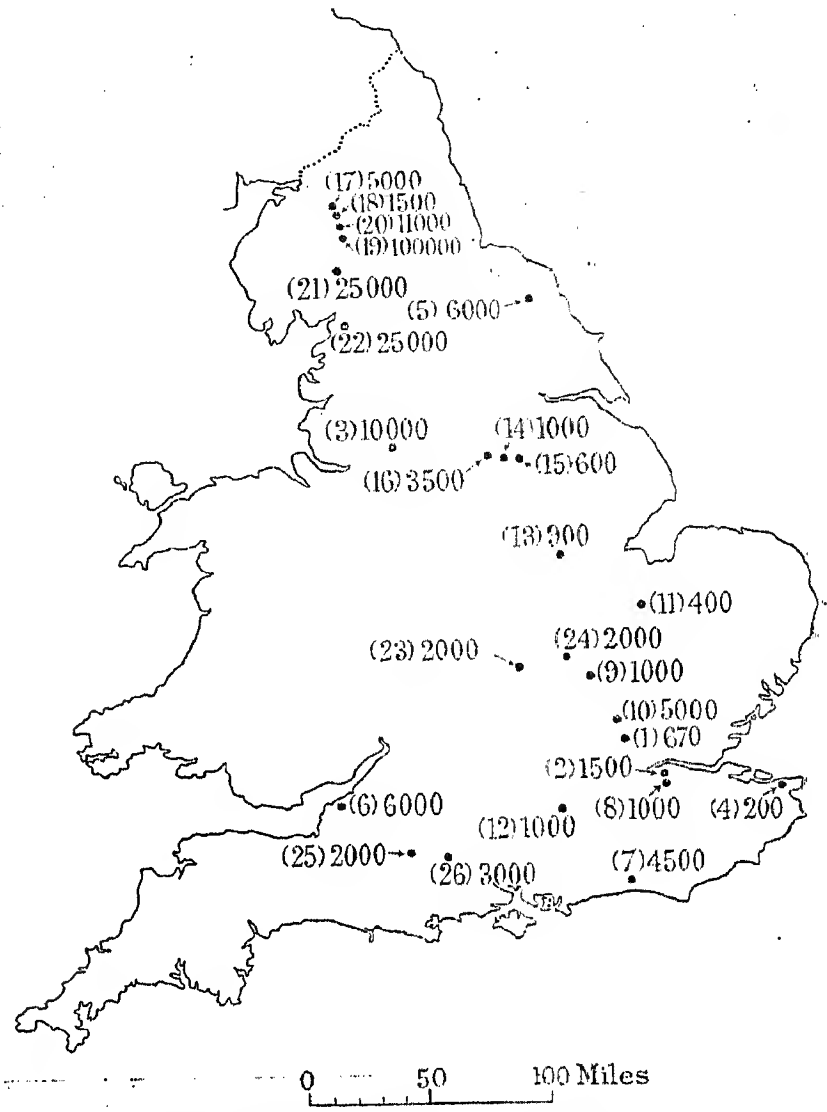

Fig. 3.—Earth-resistivity values. (The values are given in ohm-cm; the figures in brackets are the test numbers referred to in col. 1 of Table 1.)

the specific resistance of the earth at various sites in England and Italy. The majority of these tests were made using the harmonics of a power line as the inducing current. Particulars of the test sites, resistivity, and geological formation are given in Table 1.

The values of resistivity obtained in England have

Table 2

Geological formation	Resistivity, ohm-cm
Alluvium	200–400
Clay	600–1 000
Coal-bearing measures . .	2 000–5 000
Chalk	4 000–5 000
Carboniferous limestone	5 000–6 000
Sandstone	6 000–10 000
Igneous rocks	50 000–100 000

been plotted on a map (Fig. 3) in order to give an indication of the distribution in this country.

From the results given in Table 1 the summary shown in Table 2 has been obtained.

CONCLUSIONS

Experience extending over a number of years has shown that the search-coil method of measuring resistivity is quick and simple to carry out and gives results which are sufficiently accurate for use in problems of inductive interference. Comparison tests have been made* with other methods of measuring the resistivity of the earth and the results show that the search-coil values are in reasonable agreement with values obtained with the other methods.

* W. G. RADLEY and S. WHITEHEAD: *loc. cit.*

The search-coil method has the advantage that it measures the resistivity with the actual range of frequencies affecting the problem of induced noise. Its use is confined, of course, to cases where a power line, communication circuit, or other conductor, is available.

The very wide range of values obtained shows that it may be dangerous to assume a single value of resistivity for all sites, as has been done sometimes in the past, and indicates the need for resistivity measurements of this nature.

A few of the test values quoted here were obtained during tests in collaboration with the British Electrical and Allied Industries Research Association, and the remainder of the work is published with the permission of Messrs. Standard Telephones and Cables, Ltd.

DISCUSSION ON
"THE GRID-CONTROLLED RECTIFIER WITH ZERO-POINT ANODE"*

Dr. J. T. Hattingh (South Africa) (*communicated*): The basis for the author's calculation of the voltage-drop due to reactance is, I think, fallacious, although the result given in equation (28) is correct.

Referring to Fig. 14, the assumption is made that the shaded areas for overlap at angles β_1 and β_2 are equal. That this is not necessarily so, unless $L_1 = L_2$, follows directly by placing L_2 equal to zero, when the lower area should obviously be zero (no drop on the zero anode) and the upper shaded area must be carried right down to the zero axis. As a matter of fact, the drop under all conditions with zero anode can be represented by the area bounded by the two parallel lines defining β_2, by the sine curve of the anode taking up load, and by the zero axis. A formal proof may now be derived in the following way:—

Suppose a 3-phase connection with zero anode is considered. Let us consider the periods when anode (3) gives up current to the zero anode and when anode (1) takes up current from the zero anode. Let the instantaneous anode currents be i_1 for anode (1), i_3 for anode (3), and i_0 for the zero anode. Let the voltages be as follows: v = anode terminal voltage during commutation, e_1 = e.m.f. in anode (1), e_3 = e.m.f. in anode (3). Let X_1 = leakage reactance of transformer, X_2 = reactance of zero anode, x = time angle (ωt). The other symbols employed have the same meanings as in the paper.

Then
$$v = e_3 - X_1\frac{di_3}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$= -X_2\frac{di_0}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$i_0 + i_3 = I_g = \text{constant load current} \quad . \quad (3)$$

From (1) and (2),
$$v(X_1 + X_2) = e_3X_2 - X_1X_2\frac{d}{dx}(i_3 + i_0)$$
$$= e_3X_2$$

or
$$v = \frac{X_2}{X_1 + X_2}e_3 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The mean voltage across the zero anode will then be

$$-\Delta v_3 = \frac{X_2}{X_1 + X_2} \cdot \frac{m}{2\pi}E_m\int_{\pi}^{\pi+\beta_1}\sin x\,dx$$

$$= \frac{-X_2}{X_1 + X_2} \cdot \frac{m}{2\pi}E_m\int_0^{\beta_1}\sin x\,dx$$

$$= \frac{-X_2}{X_1 + X_2} \cdot \frac{m}{2\pi}E_m\frac{I_g(X_1 + X_2)}{E_m}$$

$$= \frac{-m}{2\pi}I_gX_2$$

The voltage-drop will be
$$\Delta v_3 = \frac{m}{2\pi}I_gX_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

During commutation from the zero anode to anode (1),
$$v = e_1 - X_1\frac{di_1}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$= -X_2\frac{di_0}{dx} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and
$$v = \frac{X_2}{X_1 + X_2}e_1$$

The corresponding voltage-drop is given by
$$\Delta v_1 = \frac{m}{2\pi}\int_{\alpha}^{\alpha+\beta_2}(e_1 - v)dx$$

$$= \frac{m}{2\pi}I_gX_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

The mean voltage-drop is therefore
$$\Delta V = \Delta v_1 + \Delta v_3 = \frac{m}{2\pi}(X_1 + X_2)I_g \quad . \quad . \quad (9)$$

which is equal to
$$\frac{m}{2\pi}\int_{\alpha}^{\alpha+\beta_2}e\,dx \quad . \quad . \quad . \quad . \quad . \quad (10)$$

A very simple method of calculating mean reactance-drops in a rectifier follows from the relation
$$\Delta v = \frac{m}{2\pi}\int_0^I X\frac{di}{dx}dx \quad . \quad . \quad . \quad . \quad (11)$$

where I is the current in the active anode when the other anode begins to take over. Equations (5) and (8) follow very simply. Thus
$$\Delta v_3 = \frac{m}{2\pi}\int_0^{I_g}X_2\frac{di_0}{dx}dx = \frac{m}{2\pi}I_gX_2 \quad . \quad . \quad (5)$$

and
$$\Delta v_1 = \frac{m}{2\pi}\int_0^{I_g}X_1\frac{di_1}{dx}dx = \frac{m}{2\pi}I_gX_1 \quad . \quad . \quad (8)$$

It follows then that the lower and upper shaded areas in Fig. 14 are in the ratio $X_2 : X_1$ as would be expected, and are not equal, as is implied in the author's calculation of ΔV.

The results of equations (5) and (8) may be applied

* Paper by Mr. G. I. Babat (see vol. 76, p. 397).

to the parallel rectifier if the anodes have unequal reactances; the mean voltage-drop would then be

$$\frac{1}{n}\Sigma\Delta v_n = \frac{m}{2\pi}I_g\frac{1}{n}\Sigma X_n$$

$$= \frac{m}{2\pi}I_g\overline{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where $\overline{X}$ is the mean reactance.

Mr. G. I. Babat (*in reply*): The method proposed by Dr. Hattingh for the calculation of the voltage-drop in rectifier circuits provides a more detailed picture of the effects under consideration than the method employed in the paper, but the result is the same as that given by my formula (28). Fig. 14 applies to the exceptional case where $L_1 = L_2$, but it has no influence on equations (26) and (27).

I should like to take this opportunity to give the results of an experimental investigation of a full-wave grid-controlled rectifier with zero anode. The circuit is shown in Fig. A. An inductance L_2 was specially included in the zero anode. Fig. B shows oscillograms obtained from the circuit of Fig. A with a starting angle (α) of the controlled anodes of approximately 60°. Curves 1, 2, 3, etc., in Fig. B were obtained by connecting the oscillograph across terminals 1, 2, 3, etc., in Fig. A. All the curves are photographed to the same scale.

These oscillograms confirm my theoretical curves, and they also reveal the following interesting features of zero-anode circuits. (1) The crest voltage on grid-controlled anodes never exceeds E_m (not $2E_m$ as for simple parallel circuits). (2) The inverse voltage on grid-controlled anodes increases gradually (not instantly as in parallel circuits). (3) The maximum inverse voltage on the zero anode is E_m.

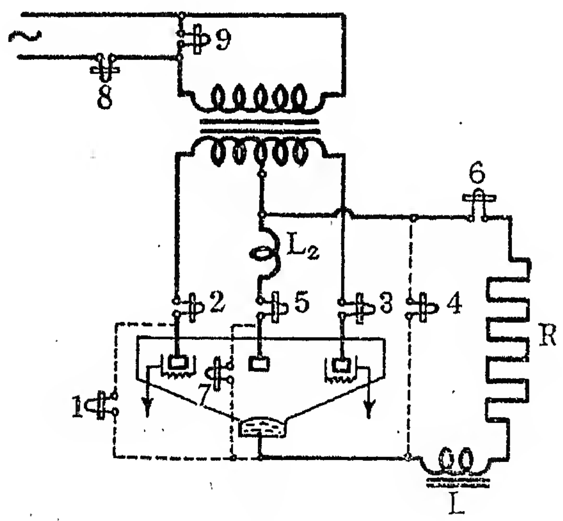

Fig. A

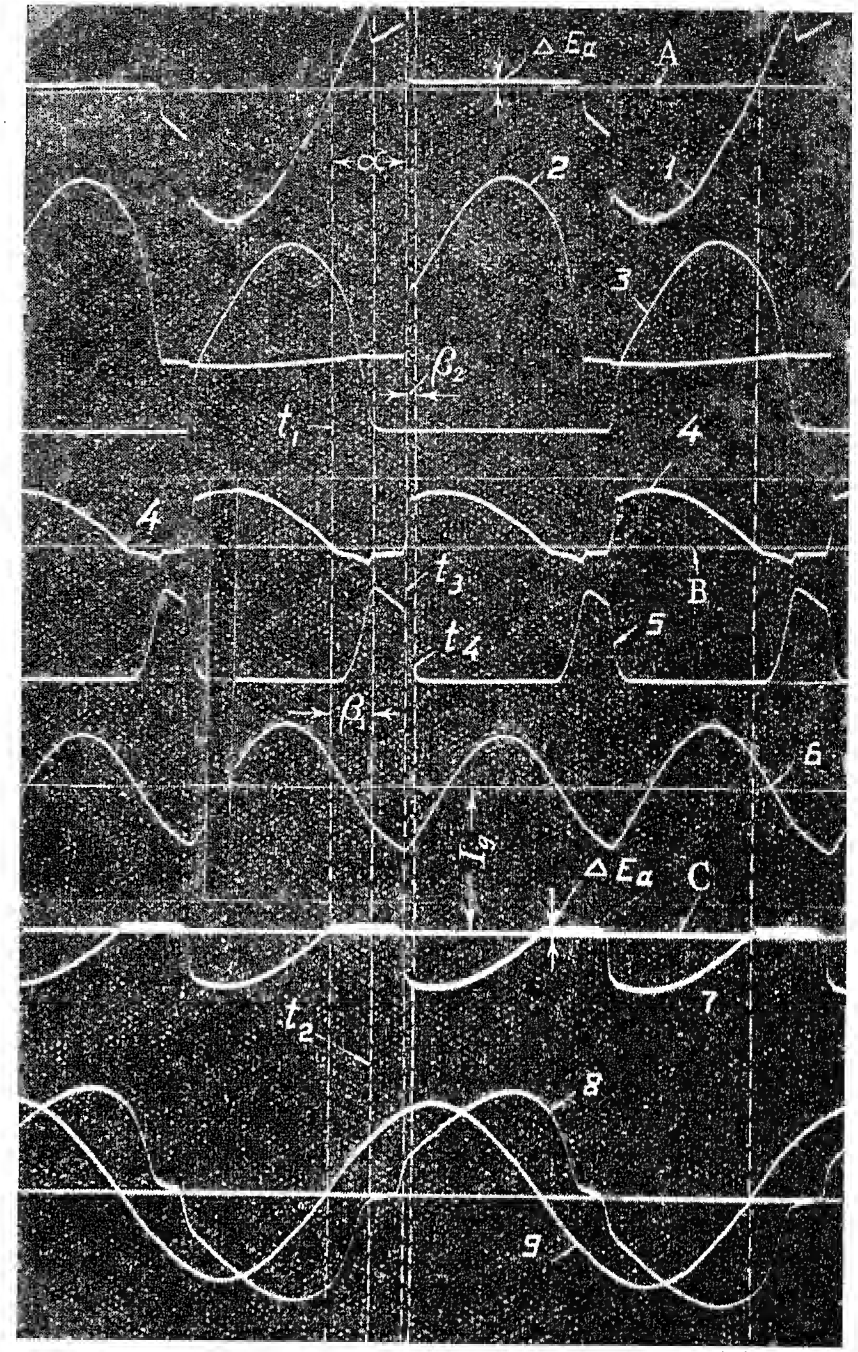

Fig. B

Curve 1. Voltage on controlled anode.
Curves 2 and 3. Controlled-anode currents.
Curve 4. Rectified voltage.
Curve 5. Zero-anode current.
Curve 6. Load current.
Curve 7. Voltage on zero anode.
Curve 8. Current in a.c. main.
Curve 9. Voltage of a.c. main.
I_g = D.C. component of load current.
ΔE_a = Voltage-drop during firing period.
A = Zero line for curve 1.
B = Zero line for curve 4.
C = Zero line for curves 6 and 7.

DISCUSSION ON
"THE PRACTICAL SOLUTION OF STRAY-CURRENT ELECTROLYSIS"*

Mr. D. W. Roper (U.S.A.) (*communicated*): Although the author has refrained from naming the Australian city which is the scene of his endeavours, it is easily identified, by referring to Reference (1), as Melbourne.

The methods used by the author, as described in this paper, should be judged by the results obtained. The only results included in the paper are given in Fig. 11, and they show that the cable faults due to electrolysis decreased from 202 in 1929 to 48 in 1933. On page 6 of the report of the Melbourne and Metropolitan Board of Works for the year ended 30th June, 1933, it is stated that the "perforations per 100 miles of steel water pipes in affected areas laid one year or longer" increased from 22 in 1929 to 27 in 1933, in spite of an increase in "electric drains connected" from 4 to 56 in the same period. Apparently, therefore, the author has included in the paper only data regarding results that are favourable to him, and has omitted equally pertinent data that are distinctly unfavourable.

Additional evidence regarding the efficacy of the author's methods may be obtained by a comparison of data regarding the number of burst cast-iron water pipes in Melbourne and in Chicago. Table A, compiled from official records, shows that, in proportion to the amount of pipe installed, there are in Melbourne 10 times as many burst cast-iron mains as in Chicago. In Chicago there are no electric drainage cables connected to the water pipes, but they are drained, incidentally, by the connection of water-cooled transformer cases to the negative busbar at a few of the railway substations, and by other similar installations.

Table A

	Chicago†	Melbourne‡
Miles of cast-iron water mains	3 723	2 589
Burst water mains repaired during year	152	1 109
Number of burst mains per 100 miles	4·05	42·8

† From the report of the Department of Public Works, Chicago, for the calendar year 1933 (pages 160 and 163).
‡ From the report of the Melbourne and Metropolitan Board of Works for the year ended 30th June, 1934 (pages 4 and 6).

The data given in Fig. 11 of the paper cannot be directly compared with experience in Chicago, as the amount of cable involved is not stated, but calculations from available data permit some comparisons. The author under heading (*c*), page 108 (vol. 76), speaks of "the high degree of immunity from electrolysis attack enjoyed by power cables, which are either armoured or laid solid in bitumen, . . ."; it will therefore be assumed that his Fig. 11 refers solely to telephone cables which, according to the records, are installed in conduits. The Commonwealth Bureau of Census and Statistics reports† that on the 30th June, 1933, there were 1 884 duct-miles of conduit for telephone cables in the State of Victoria. Under American conditions it would require about 1 000 miles of cable to supply the telephones in the Melbourne area, but in the present case it will be assumed that the conduits are being fully utilized, so that there are in these conduits a total of 1 884 miles of cable. Applying this figure to the data in Fig. 11, and assuming the same amount of cable in 1929, we find that the number of cable faults caused by electrolysis per 100 miles of cable was reduced from 107 in 1929 to 25·5 in 1933. In Chicago the Commonwealth Edison Co., with 4 090 miles of cable installed in 1934, averaged 3·4 cable faults due to electrolysis per year in the same 5-year period, or 0·83 failure per 100 miles of cable per year. The telephone company in Chicago have not published their records for such troubles, but private information from their engineers is to the effect that, with slightly less cable than the Edison company, they have obtained practically identical results. This means that the author, having reduced the number of cable faults due to electrolysis per 100 miles of cable from 130 times the Chicago record in 1929 to 30 times in 1933, and with the perforations of steel pipes increasing in the same period, claims to have achieved "the practical solution of stray-current electrolysis."

Table B†

Comparison of Conditions in Chicago and Melbourne.

	Chicago	Melbourne
Population	3 376 000	1 028 000
Max. electric traction load, kW	325 090	69 800
Max. electric traction load, amps.	513 900	60 800
Number of crossings of tracks..	117	60‡
Number of crossings per 100 000 amps. in return circuits at time of max. load	23	98
Number of substations ..	53	42
Average max. amps. per substation	9 660	1 440

† Compiled from standard statistical publications.
‡ Estimated after allowing for the fact that only 80 per cent of tramways shown in Fig. A are electrified.

Under the heading "Comparative Costs of Mitigative Measures" the author mentions on page 109 "the

* Paper by Mr. C. M. Longfield (see vol. 76, pp. 101 and 577).

† *Transport and Communication Bulletin*, No. 24, p. 25, Table 77.

reduction of rail potentials," i.e. the reduction of the voltage-drop in the rails. Later, under the same heading, he calculates the cost of reducing rail potentials by (*a*) copper cables in parallel, and (*b*) graded negative feeders. Then he adds: "Enough has been said to indicate how expensive mitigative measures become, if applied only to the traction network. It must also be pointed out that expenditure as indicated above is a dead loss to the traction authority." The author has failed to consider the interconnection of the return circuits of the rival overlapping traction system in Melbourne as a method of reducing rail potentials, although this method—described by me in 1918*—is included by the author in the list of references appended to his previous paper on a similar subject.* In my paper it was shown that, under the most favourable local conditions, the reduction in rail potential would be 75 per cent. Such interconnections would therefore result in a considerable reduction in the loss of energy in the return circuits, so that the cost of the interconnections would not be a "dead loss to the traction authority." A comparison of the map of the traction systems in Melbourne (Fig. A) with a similar map of Chicago (Fig. B) shows that the conditions are very similar in the two cities; in fact, a tabular statement of the conditions in the two cities (Table B) shows that in proportion to the amount of current in the return circuits during the maximum-load period, there are oppor-

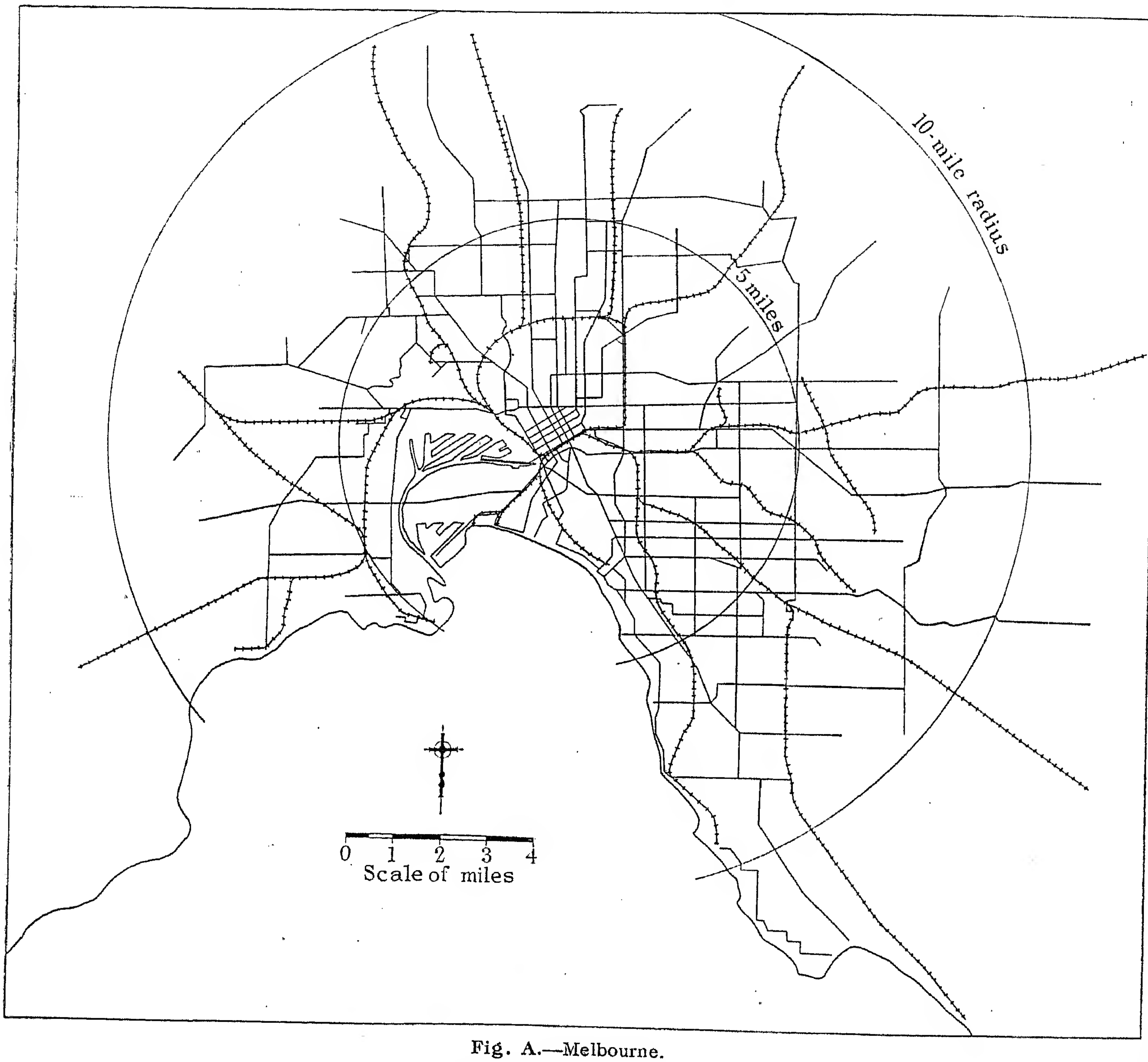

Fig. A.—Melbourne.

Electrified tramways, 600 volts, d.c.
Electrified suburban railway, 1 500 volts, d.c.

* *Electric Railway Journal*, 1918, vol. 52, p. 1005.

* *Journal of the Institution of Engineers, Australia* 1931 vol. 3, p. 157.

tunities for four times as many such interconnections in Melbourne as in Chicago. The author mentions the two traction systems in his remarks regarding Fig. 11, but nowhere in his paper does he indicate that he is aware of the fact that the presence of two traction systems with their independent return circuits is of vital importance in regard to the solution of the electrolysis problem in Melbourne. In Chicago, where the map of the traction systems (Fig. B) shows 117 crossings, there are 156 interconnections—showing that there are many interconnections where the tracks of the two systems are parallel. The corresponding Melbourne map (Fig. A) shows many similar opportunities. Perhaps the authorities of the electrified suburban railway object to such interconnections because they would interfere with their system of a.c. automatic signals* unless expensive reactance bonds were used; but the elevated lines in Chicago have a system of automatic signals that is not disturbed by 156 interconnections with the surface lines. These interconnections, and a drainage system, are responsible for the favourable record of failures on the cable system of the Commonwealth Edison Co.

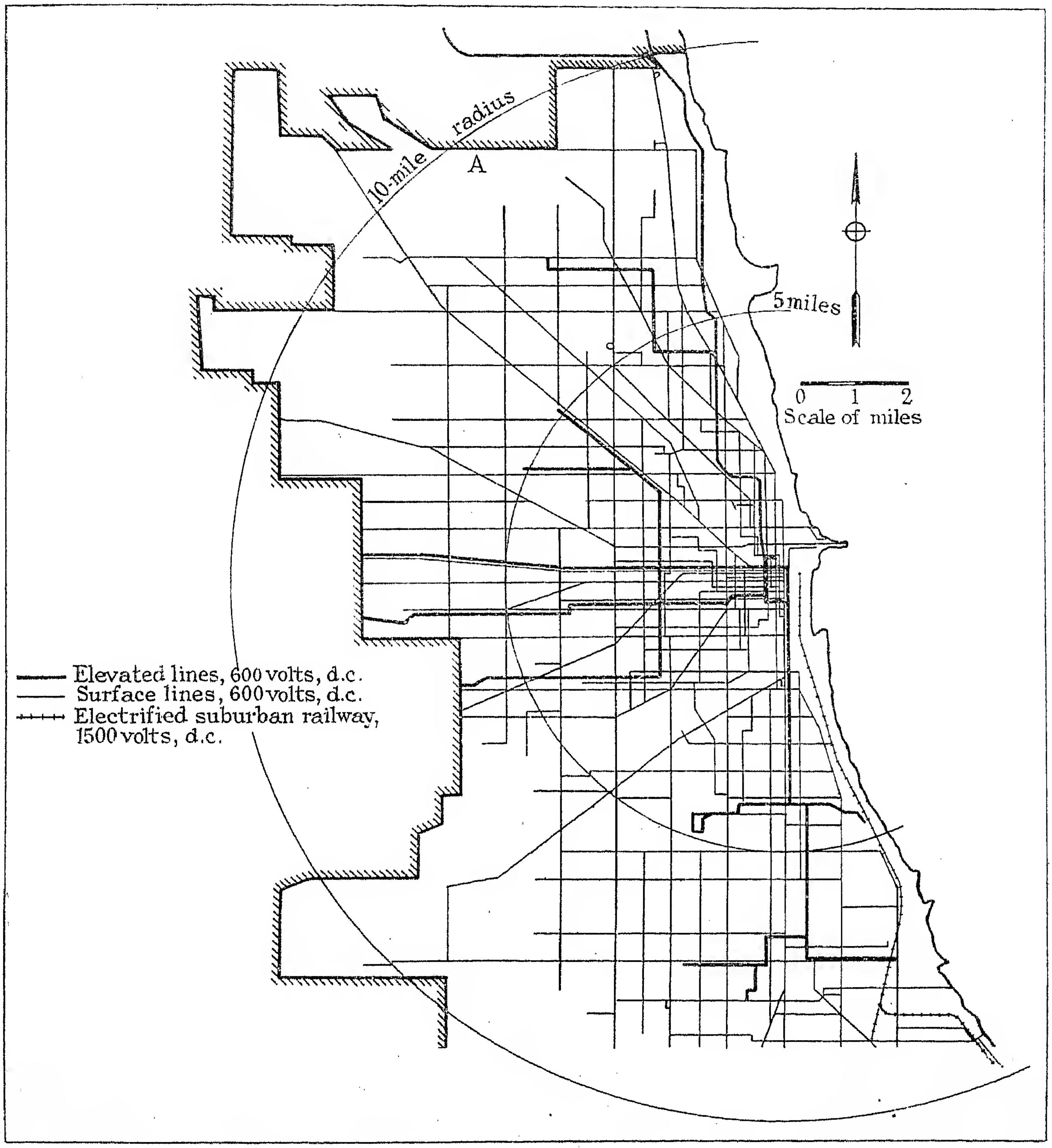

Fig. B.—Chicago.

In connection with his comments on Fig. 11, the

* *Engineering*, 1920, vol. 109, p. 10.

author states that 73 bonds, each including a copper-oxide rectifier, have been connected to the cables. In Chicago there is only one bond including a copper-oxide rectifier and that is located at point A (Fig. B) and is connected to the rails of a suburban electric railway, about $1\frac{1}{2}$ miles beyond the city limits.

The author quite correctly states (page 107) that "The objective in electrical drainage is the elimination of those positive areas on a buried conduit from which current is discharging to earth." He has failed to note, however, that at locations where the electric traction systems cross, the conduit will, in general, assume an intermediate potential; or, in other words, the conduits will be positive to one set of tracks. It will therefore be impossible to realize his objective until the two sets of tracks have been thoroughly interconnected. The records of cable faults and pipe perforations indicate that there must be many such areas which the author attempts to excuse, or to justify, where he says (page 102): "Except in relatively simple cases, it cannot be taken for granted that, because a metal conduit is found to be positive to an electrified track, it is losing current to it; . . ." This statement says that there may be a difference of potential across a resistance without any current flowing; in other words, the author renounces Ohm's law.

He devotes nearly two pages to the heading "Electrical Tests for Electrolysis," and additional discussion of the same subject appears under the heading "Field Instruments." In Chicago I have found that high-resistance indicating and recording voltmeters satisfy all the requirements for field tests. The millivolt scale on the indicating instruments permits determinations of the drainage current in the field with sufficient accuracy. In each railway substation the total drainage current is shown by a switchboard ammeter, whose readings are recorded by the substation operator.

Under the heading "Substation operations and load characteristics" (page 106) the author states that his problem is rendered more difficult because the substations are operated in multiple; also that the protection of localized lead-covered cable networks by electrical drainage is generally impracticable. Under the heading "Drainage Bonding" (page 107) he states: "In general, this method of protection is really only applicable to a restricted area around the negative rail taps . . ."; and under the heading "Zinc Plates" (page 109) he discusses the difficulties of protecting cable laterals. In Chicago, each of the traction systems operates all of its substations in parallel, and, in addition, at about one-third of the substations the elevated lines and the surface lines are supplied from a common positive busbar. The drainage system is applied throughout the city, including isolated networks and cable laterals. The author's statements are probably correct as applying to conditions in Melbourne, but, in view of the low records of cable faults in Chicago, his remarks must be regarded as practical evidence of the impossibility of successfully draining the conduits to two independent, overlapping negative return systems at the same time.

Mr. C. M. Longfield (*in reply*): The methods described in the paper were evolved as a result of investigations in Melbourne, but the same methods have been applied, either by myself or by others who have made a close study of the Melbourne Committee's methods, in a number of other cities ranging in population from 30 000 to 300 000. In all cases but one, complete success has already been achieved in these cities; that is, no faults are now reported.

Mr. Roper is quite wrong in drawing the conclusions he does from the reports of the Melbourne and Metropolitan Board of Works for 1932–33. Not only has he fallen into error in saying what he does, but his remarks are directly opposed to those contained in the report itself, which states:

"As an instance of the reduction of failures effected by means of the installation of an electric drainage system, the record of perforations on the 46-inch mild-steel Merri Creek to Richmond main may be cited.

"Year	Cost of repairs	Perforations	Remarks
	£		
1928–1929	47	2	Main laid in July, 1928
1929–1930	139	3	Electric drainage connected in February, 1932
1930–1931	170	7	
1931–1932	232	13	
1932–1933	nil	nil	

"A section of this main would have had its economic life reduced from 50 to less than 10 years if the rate of increase of perforations from 1928 to 1932 had been maintained for another 6 years.

"Similar improvements have been effected in many other areas. It will be seen from the following table that the number of perforations per 100 miles of steel pipe per annum is being gradually reduced. The peak period occurred in 1925–1926, shortly after a period of intensive traction electrification.

"Year	Perforations	Mileage*	Perforations per 100 miles	Electric drains connected
1920–1921	16	103	16	nil
1921–1922	37	108	34	nil
1922–1923	61	114	53	nil
1923–1924	60	114	53	nil
1924–1925	74	118	63	nil
1925–1926	82	127	65	nil
1926–1927	67	153	44	1
1927–1928	66	173	38	2
1928–1929	45	203	22	4
1929–1930	48	243	20	6
1930–1931	54	263	21	11
1931–1932	87	265	33	29
1932–1933	71	266	27	56

* That is, mileage of steel pipes in affected areas laid 1 year or longer."

It must be pointed out that the reduction in faults is not directly proportional to the number of drainage bonds installed in the case of the water mains, as 50 per cent of the drains were applied at points within a $\frac{1}{2}$-mile

radius of which no faults have been reported, but where electrical tests suggested their application.

The data collected in Table A of Mr. Roper's communication are not relevant. I am in a position to say that, after some years of careful inspection, evidence of stray-current corrosion has so far not been forthcoming to any appreciable extent on the cast-iron water and gas mains in Melbourne. The large difference between the Chicago and Melbourne figures is probably due, among other things, to the generally higher water pressure in use in the latter city. Moreover, in the temperate climate of Melbourne, pipes were in the past laid at much shallower depths than in Chicago, where severe frost conditions at times prevail. The cover in roadways over such pipes in Melbourne has proved insufficient to withstand the impact of modern fast-moving and heavy motor traffic. The stresses so caused, associated with a generally damp and plastic soil structure, have largely added to bursts on cast-iron water mains.

There were three reasons why I did not include data concerning water mains in my paper:—

(*a*) The paper sets out to indicate the principles of analysis and the design of mitigative measures, and was not intended to include a description of any particular locality.

(*b*) The protection of large steel water mains is a particularly difficult matter and is vastly complicated by the interchange of current between parallel pipes and by other matters quite beyond the scope of my short paper.

(*c*) The measures proposed for the better protection of these pipes had not been fully applied throughout the Melbourne area when the paper was written.

In those instances where the methods described in the paper have been applied, faults on steel water mains have definitely been checked.

Mr. Roper rightly concludes that Fig. 11 applies to Melbourne, but it covers the history of faults on about 1 500 miles of power cables, as well as a similar mileage of telephone cables. In discussing the relative incidence of faults in Melbourne and Chicago, surely Mr. Roper intends 10·7 and 2·55 faults per 100 cable-miles per annum instead of 107 and 25·5 respectively. This correction would imply a corresponding correction later in the same paragraph.

In comparing the effect of electrolysis upon telephone and power cables, it may be of interest to note the following figures which were compiled from statistics in an area where about 700 miles of telephone cables were subjected to substantially the same electrolysis hazard as the 1 500 miles of power cables noted above. Over a 3½-year period, and before electrical drainage was seriously applied, 14·2 telephone-cable faults were reported per 100 miles per annum, whilst the corresponding figure for the power-cable networks was 0·13 fault per 100 cable-miles per annum, which compares more than favourably with the cable history of the Commonwealth Edison Co., even when protective measures had been applied.

As I did not refer specifically to the interconnection of "rival" rail systems in my paper, I must repeat that the reduction of rail-drops by the installation of graded negative feeders is a dead loss to the traction authority. It is, of course, sometimes feasible and economical to reduce rail potentials by the interconnection of rails, as suggested by Mr. Roper, but I am sure that Mr. Roper would agree that this should only be done when the leakage current escaping to earth will thereby be reduced. In the Melbourne case this point has been carefully considered, but it was found that, for the most part, such interconnection would result in part of the heavy railway currents being diverted into the tramway rails, thus adding to the drop in the latter, as, with few exceptions, currents flow in the same general direction in both rail systems. As the track leakage resistance of the tramway system is much less than that of the ballasted suburban railway system, the stray earth currents would be materially increased. This result would have been rather more evident had Mr. Roper obtained a plan (with substations located) of the Melbourne systems as they really exist. Mr. Roper's Fig. A is very much in error, especially as regards the tramway system, which is not nearly as extensive or as interconnected as he shows. Moreover, the amount of ballasted track in Chicago is insignificant compared with that of the suburban railway system in Melbourne, which is ballasted throughout, and, furthermore, the latter operates at 1 500 volts, while the local tramway or street-car system operates at 600 volts. Thus, complete interconnection of the positive and negative sides is quite impossible.

The use of copper-oxide rectifiers in drainage bonds has been fully justified in Melbourne over a period of many years.

The conditions in Melbourne, especially as regards large steel pipes, have made highly refined methods of test necessary. The presence of different metals and of highly conducting soil has meant that the electrode potentials of the half cells comprising the conduits and adjacent soil have had to be eliminated before reliance could be placed upon potential readings. For example, a lead-covered cable might normally be found to be 0·2 volt positive to a local rail in the entire absence of stray traction currents. This electrode effect, which may vary over fairly wide limits, is present in all potential readings, and the discussion in the paper concerning such observations is perfectly valid. There has, therefore, been no renunciation of Ohm's law, as suggested by Mr. Roper.

The protection of conduits in an area influenced by two independent traction systems has not been particularly troublesome. In the last paragraph of his communication, Mr. Roper refers to the protection of isolated cable systems. The related passages in the paper were intended to indicate the difficulties of protecting, by electrical drainage, isolated cable systems occurring, say, in rail positive areas where the outflow of current from the rails causes a discharge of current from cable-ends some distance from the track. Such cases present difficulties which would not be solved by merely interconnecting rival rail systems.

The main feature of Mr. Roper's criticism is the emphasis he lays upon the interconnection of the rail systems. This proved relatively simple in Chicago, and in any case was probably highly desirable to protect the steel footings of the elevated railway. There is reason

to believe that other things were done in Chicago, the cost of which must have been considerable (I refer to the effect of various city ordinances), but, without the closest personal scrutiny of the conditions, I would not venture an opinion as to their soundness.

The thesis implied in my paper is that the practical solution of stray-current electrolysis depends upon (*a*) complete co-operation between the utilities, (*b*) properly designed and controlled electrical drainage as a pre-requisite to other measures, and (*c*) the introduction of other measures should these then prove necessary.

PROCEEDINGS OF THE INSTITUTION

887TH ORDINARY MEETING, 24TH OCTOBER, 1935.

Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., the retiring President, took the chair at 6 p.m.

The minutes of the Annual General Meeting held on the 16th May, 1935, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The Chairman announced that, during the period May to September, 607 donations and subscriptions to the Benevolent Fund had been received, amounting to £555. A vote of thanks was accorded to the donors.

The Premiums (see vol. 76, page 717, and vol. 77, page 147) awarded for papers read or published during the past session were presented by the Chairman to such of the recipients as were able to be present.

Prof. Thornton then vacated the chair, which was taken by the new President, **Mr. J. M. Kennedy, O.B.E.,** amid applause.

Mr. C. C. Paterson: It has been the practice for many years to ask a Past-President to express the thanks of the Institution to the retiring President. The first thing a retiring President has to do is to readjust his sense of proportion. I believe it was Thucydides who said that a balanced view is difficult when every man imagines that important events are confined to his own vicinity. I suppose no one has more justification for feeling like that than the President for the time being of the Institution; but our retiring President will have least trouble of all men in readjusting his sense of values, for throughout his term of office he has had but one aim—to efface himself and to serve the Institution in all its activities and in all its phases. He has done this with dignity and with ability, and he has never spared himself one moment. We are fortunate still to have in our counsels a man like Prof. Thornton, who views the electrical industry as a whole and neither overrates nor underrates the importance of any one of its constituent parts. I know that he will look back on his year of office with very great pleasure, but he can also feel assured that we shall do so too. Although the words of the resolution which has been put into my hands are the same as those used when in the past each President has vacated the chair, it is in no spirit of formality that I ask you to support the following resolution: "That the best thanks of the Institution be accorded to Professor W. M. Thornton for the very able manner in which he has filled the office of President during the past year."

Mr. W. E. Highfield: Mr. Paterson has eloquently described the activities of Prof. Thornton. I should like to stress two points only—first, that Prof. Thornton seems to have so accurately balanced the scientific with the practical that it would be almost impossible to overstress the value of the work which he has done for the industry. Secondly, upon a slightly more personal note, the public duties performed by our President are evident, but those are not the whole of his duties: only those who have worked with Prof. Thornton know the volume and the quality of the work that he has done for the Institution, the help so readily given to anyone who needed it, and the kindness with which that help was given. I most heartily second the vote of thanks.

The resolution was then carried with acclamation.

Prof. W. M. Thornton: I shall never have in all my life such kind words said about me as those I have just heard from Mr. Paterson and Mr. Highfield. Whether they are true or not is in the invisible records which are not the records of the Institution. But I hope, indeed, that they are true. There is no doubt that anyone who takes on the work of President of the Institution does a great deal of hard work and hard thinking. He himself is conscious of it, but other people may not be; but I can assure you that it would be very much harder if it were not for the way in which the work of the Institution is carried on by Mr. Rowell and his staff. I can only say how grateful I am to them for the way in which they have supported me during the past year. There is one last word which I should like to say to the new President. It is this—that I have noted while I have been on the Council that Presidents in years gone by have either become a little older or a little rounder during their year of office. I leave the choice with you, Sir.

The President then delivered his Inaugural Address (see page 1).

Mr. J. M. Donaldson: I have to propose "That the best thanks of the Institution be accorded to Mr. J. M. Kennedy for his interesting and instructive Presidential Address and that, with his permission, the Address be printed in the *Journal* of the Institution." Many of us who are perhaps more closely connected with electricity distribution than Mr. Kennedy himself is are very glad to have what I might perhaps call a partial outside view.

I think that is a fair way of putting it. The fact of the matter is that people who are actively engaged in distribution are at present so extraordinarily busy that they have very little time to cast an eye over their own affairs and to make far-flung plans for the future. Therefore we are very grateful to Mr. Kennedy for the very thorough way in which he has gone over the ground and for his enthusiastic ideas on the subject. There is one note on which I should like to dwell in conclusion, and that is that for the first time we have in the Presidential Chair of this Institution a " working " Electricity Commissioner. Although Sir John Snell, the first Electricity Commissioner, was President of this Institution, that was in 1914 before Electricity Commissioners had been invented. On the other hand, Sir Archibald Page was our President when he had ceased to be a Commissioner.

Mr. P. V. Hunter: It is with the greatest possible pleasure that I second the motion of thanks to my old friend Mr. Kennedy. I think I am able to claim him as an old friend because, if my recollection serves me correctly, we first met some 35 years ago in the testing room of the works of Messrs. Willans and Robinson at Rugby. Even at that early date he displayed those qualities of intellect and character which are so clearly exemplified in the Address to which we have just listened, and we pupils all regarded him as someone who was destined for a great career. I think that in the case of this Address particularly we have a feeling of regret that it is against the practice of the Institution formally to discuss Presidential Addresses, as this one would without doubt lead to a most interesting and informative discussion. Notwithstanding the ban on formal discussion, however, I am satisfied that during the next few weeks the Address will be the subject of very interesting personal discussion among members both in the provinces and in London, and that in this way the message which Mr. Kennedy has so illuminatingly communicated to us will be brought home to all.

The vote of thanks was carried with acclamation and, after the President had briefly replied, the meeting terminated.

INSTITUTION NOTES

NATIONAL CERTIFICATES AND DIPLOMAS IN ELECTRICAL ENGINEERING

The following are the results of the examinations in connection with the above for the year 1935:—

England and Wales.

	Pass	*Fail*
Ordinary Certificate	737	629
Higher Certificate	438	210
Higher Certificate endorsed ..	61	19
Ordinary Diploma	15	9
Higher Diploma	7	6
	1 258	873

Scotland.

Ordinary Certificate	20	12
Higher Certificate	6	2
Higher Diploma	17	4
	43	18

MASCART MEDAL

The Société Française des Électriciens have decided to make the next award (1936) of the above Medal to Professor A. E. Kennelly, D.Sc., who is an Honorary Member of The Institution.

PORTRAITS OF PIONEERS IN COMMUNICATION ENGINEERING

The Bureau de l'Union Internationale des Télécommunications propose to publish each year a portrait of one of the pioneers in communication engineering (telegraphy, telephony, and wireless). The first to be published is one of Samuel Morse, in the form of an etching by a well-known artist. The overall size of the portrait is 23 cm by 18 cm. The price, including postage, is 2 Swiss francs per copy, and any member of the Institution who desires to obtain one should apply to the above Bureau, at Effingerstrasse No. 1, Berne, Switzerland.

The portrait proposed to be published next year is that of David Hughes.

LOCAL CENTRE COMMITTEES ABROAD

The present constitution of the Local Centre Committees abroad is as follows:—

Argentine

K. N. Eckhard. R. G. Parrott.
F. Harris. H. C. Siddeley.
H. J. McPhail. L. P. Thomson.
G. W. Munday. W. S. Wheeler.
R. Wright.

China

C. R. Webb (*Chairman*).
S. Y. Chang. A. H. Gordon.
N. Denison. J. A. McKinney.
S. Flemons. C. M. Perrin.
W. C. Gomersall.
J. Haynes Wilson, M.C. (*Hon. Secretary*).

LOCAL COMMITTEES ABROAD

The present constitution of the Local Committees abroad is as follows:—

Australia

NEW SOUTH WALES.

V. L. Molloy (*Chairman*).

V. J. F. Brain. R. V. Hall, B.E.
L. F. Burgess, M.C. A. S. Plowman.
W. R. Caithness. P. S. Saunderson.
E. F. Campbell, B.Eng.

W. J. McCallion, M.C. (*Hon. Secretary*).

QUEENSLAND.

W. M. L'Estrange (*Chairman*).

W. Arundell. F. Walker.
A. Boyd, D.Sc.

J. S. Just (*Hon. Secretary*).

SOUTH AUSTRALIA.

F. W. H. Wheadon (*Chairman and Hon. Secretary*).

E. V. Clark. W. Inglis.
J. S. Fitzmaurice. P. Kennedy.
Sir W. G. T. Goodman. D. E. McLaren.

VICTORIA AND TASMANIA.

H. R. Harper (*Chairman and Hon. Secretary*).

F. W. Clements. H. C. Newton.
J. M. Crawford. T. P. Strickland.
R. J. Strike.

WESTERN AUSTRALIA.

J. R. W. Gardam (*Chairman*).

F. C. Edmondson. S. Johnson.
Prof. P. H. Fraenkel, B.E. W. H. Taylor.

A. E. Lambert, B.E. (*Hon. Secretary*).

Ceylon

Major C. H. Brazel, M.C. (*Chairman*).

J. M. Baxter. D. K. Mukherji.
C. H. Jones. J. Shillitoe.
G. E. Misso. D. de S. Weerasena.

G. L. Kirk (*Hon. Secretary*).

India

BOMBAY.

S. E. Povey (*Chairman*).

C. M. Cock. E. G. Lazarus.
K. M. Dordi. F. O. J. Roose.
R. G. Higham. H. J. Seale.

A. L. Guilford (*Hon. Secretary*).

CALCUTTA.

F. T. Homan (*Chairman*).

H. J. Allinson. P. S. E. Jackson.
N. C. Bhattacharji. S. W. Redclift.
C. R. Bland. F. W. Sharpley.
C. C. T. Eastgate.

D. H. P. Henderson (*Hon. Secretary*).

LAHORE.

Prof. T. H. Matthewman (*Chairman*).

A. T. Arnall. H. J. Darling.
J. C. Brown, B.Sc. M. O. Sidiqui.
B. Paul.

H. F. Akehurst, B.Sc. (*Hon. Secretary*).

New Zealand

F. T. M. Kissel, B.Sc. (*Chairman*).

R. H. Bartley. E. Hitchcock.
M. C. Henderson.

J. McDermott (*Hon. Secretary*).

South Africa

TRANSVAAL.

W. Elsdon Dew (*Chairman and Hon. Secretary*).

J. B. Bullock. Prof. O. R. Randall, Ph.D., M.Sc.
S. E. T. Ewing. A. Rodwell.
V. Pickles. L. B. Woodworth.
B. Price.

COMMITTEES, 1935–1936

Among the Committees appointed* by the Council for 1935–1936 are the following:—

Benevolent Fund Committee

The President (*Chairman*).

A. H. M. Arnold, D.Eng. ..
J. R. Beard, M.Sc. .. ..
F. W. Crawter .. ..
V. Z. de Ferranti .. ..
W. McClelland, C.B., O.B.E.
Johnstone Wright .. .. } representing the Council.

J. F. W. Hooper .. ..
P. Rosling .. .. ..
J. F. Shipley .. .. .. } representing the Contributors.

And the Chairman of each Local Centre in Great Britain and Ireland.

Informal Meetings Committee

M. Whitgift (*Chairman*).

G. F. Bedford. L. M. Jockel.
H. Brierley. A. F. W. Richards.
Forbes Jackson. J. F. Shipley.
S. B. Jackson. F. Jervis Smith.

And

A representative of the General Purposes Committee.
The Chairman of the Papers Committee.
The Chairman of the London Students' Section.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (England and Wales)

W. E. Highfield .. ..
Prof. E. W. Marchant, D.Sc.
Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng. .. } representing the I.E.E.

F. T. Chapman, D.Sc. ..
A. Morley, D.Sc. .. ..
H. J. Shelley, B.Sc. .. } representing the Board of Education.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (Scotland)

Prof. G. W. O. Howe, D.Sc.
D. S. Munro .. .. ..
R. Robertson, B.Sc. .. ..
Prof. S. Parker Smith, D.Sc. } representing the I.E.E.

Dr. J. S. W. Boyle .. ..
J. G. Frewin .. .. ..
W. Hyslop .. .. ..
F. W. Michie .. .. .. } representing the Scottish Education Department.

* The President is, *ex-officio*, a member of all Committees of the Institution.

Local Centres Committee

A. P. M. Fleming, C.B.E., M.Sc.
F. Gill, O.B.E.
J. S. Highfield.
E. W. Moss.
F. E. J. Ockenden.
Col. Sir Thomas F. Purves, O.B.E.
J. W. Thomas, LL.B., B.Sc.Tech.

And the Chairman of each Local Centre and Sub-Centre.

Meter and Instrument Section Committee

Chairman: O. Howarth.
Vice-Chairman: G. F. Shotter.
Past-Chairman: Prof. J. T. MacGregor-Morris.

H. P. Bramwell.
B. S. Cohen, O.B.E.
S. James.
F. C. Knowles.
B. H. Leeson.
H. B. Nield.
H. S. Petch, B.Sc.(Eng.).
A. J. Pitt.
E. S. Ritter.
R. S. J. Spilsbury, B.Sc. (Eng.).
H. C. Turner.
J. G. Wellings.

And

A representative of the Council.
The Chairman of the Papers Committee.

Overseas Activities Committee

Sir Noel Ashbridge.
Lieut.-Col. K. Edgcumbe, T.D.
W. G. Hendrey.
J. S. Highfield.
C. Le Maistre, C.B.E.
C. C. Paterson, O.B.E.

And

The Chairman of the Finance Committee.
The Chairman of the General Purposes Committee.
The Chairman of the Membership Committee.
The Chairman of the Papers Committee.

Also the following co-opted members:—

Prof. J. K. Catterson-Smith, M.Eng.
W. P. Gauvain.
F. Gill, O.B.E.
A. S. Herbert.
A. C. Kelly.
F. Lydall.
J. T. Mertens.
E. A. Mills.
H. Nimmo.
E. E. Sharp.
A. L. Stanton.
C. S. Taylor.
V. Watlington, M.B.E.

Scholarships Committee

Prof. J. K. Catterson-Smith, M.Eng.
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W. H. Eccles, D.Sc., F.R.S.
Prof. J. T. MacGregor-Morris.
Prof. E. W. Marchant, D.Sc.
H. Marryat.
R. W. Paul.
Prof. E. L. E. Wheatcroft, M.A.
Johnstone Wright.

"Science Abstracts" Committee

L. G. Brazier, Ph.D., B.Sc.
Prof. J. T. MacGregor-Morris.
C. C. Paterson, O.B.E.
R. S. Whipple.

And	*Representing*
J. H. Awbery, B.A., B.Sc.	Physical Society.
A. Ferguson, M.A., D.Sc.	Physical Society.
D. Owen, B.A., D.Sc.	Physical Society.
Prof. G. F. J. Temple, D.Sc., Ph.D.	Physical Society.
Prof. G. P. Thomson, M.A., F.R.S.	Royal Society.

Ship Electrical Equipment Committee

A. G. S. Barnard.
Major B. Binyon, O.B.E., M.A.
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Dr. P. Dunsheath, O.B.E., M.A.
S. Harcombe, M.A., B.Sc.
A. Henderson.
J. F. W. Hooper.
P. V. Hunter, C.B.E.
J. W. Kempster.
A. Cecil Livesey.
W. McClelland, C.B., O.B.E.
S. W. Melsom.
N. W. Prangnell.
Col. A. P. Pyne.
T. A. Sedgwick.
H. D. Wight.
Ernest T. Williams, O.B.E.

And	*Representing*
H. Cranwell	Board of Trade.
W. T. Williams, O.B.E.	Board of Trade.
B. Hodgson	British Corporation Register of Shipping and Aircraft.
T. R. Thomas	British Corporation Register of Shipping and Aircraft.
T. Ratcliffe	British Electrical and Allied Manufacturers' Association.
C. W. Saunders	British Electrical and Allied Manufacturers' Association.
W. Cross	Electrical Contractors' Association.
S. B. Jackson	The Institute of Marine Engineers.
A. E. Laslett	The Institute of Marine Engineers.
J. F. Nielson	Institution of Engineers and Shipbuilders in Scotland.
W. J. Belsey	Institution of Naval Architects.
S. F. Dorey, D.Sc.	Lloyd's Register of Shipping.
G. O. Watson	Lloyd's Register of Shipping.
W. S. Wilson	North-East Coast Institution of Engineers and Shipbuilders.

And

A representative of the Electrical Contractors' Association of Scotland.

Transmission Section Committee

Chairman: W. Fennell.
Vice-Chairman: Dr. P. Dunsheath, O.B.E., M.A.
Past-Chairman: R. Borlase Matthews.

W. C. Bexon.
J. H. C. Brooking.
J. M. Donaldson, M.C.
B. Handley.
P. V. Hunter, C.B.E.
F. W. Main.
C. F. Mounsdon.
F. W. Purse.
Major T. Rich, O.B.E.
S. R. Siviour.
R. J. J. Swan.
Johnstone Wright.

And

A representative of the Council.
The Chairman of the Papers Committee.
The following representatives of Government Departments:—
Central Electricity Board: C. W. Marshall, B.Sc.
Electricity Commission: C. G. Morley New.
Post Office: P. J. Ridd.

Wireless Section Committee

Chairman: R. A. Watson Watt, B.Sc.(Eng.).
Vice-Chairman: A. J. Gill, B.Sc.(Eng.).
Past-Chairman: S. R. Mullard, M.B.E.

Sir Noel Ashbridge.
H. Bishop, B.Sc.(Eng.).
S. Brydon, D.Sc.
W. T. Ditcham.
N. F. S. Hecht.
J. Joseph.
A. H. Mumford, B.Sc.(Eng.).
W. F. Rawlinson, D.Sc.
Frederick Smith.
R. L. Smith-Rose, Ph.D., D.Sc.
C. E. Strong, B.A.I.
W. Ure, B.Sc.

And

A representative of the Council.
The Chairman of the Papers Committee.
The following representatives of Government Departments:—
Admiralty: Capt. W. T. Makeig-Jones, R.N.
Air Ministry: F. S. Barton, M.A., B.Sc.
Post Office: A. J. Gill, B.Sc.(Eng.).
War Office: Col. J. P. G. Worlledge, O.B.E.

Wiring Regulations Committee

Ll. B. Atkinson.	P. V. Hunter, C.B.E.
H. J. Cash.	H. Marryat.
J. R. Cowie.	S. W. Melsom.
Dr. P. Dunsheath, O.B.E., M.A.	F. W. Purse.
	Col. A. P. Pyne.
P. Good.	H. W. H. Richards.
R. Grierson.	E. Ridley.
J. F. W. Hooper.	

And	*Representing*
A. C. Sparks	Association of Consulting Engineers.
A. Kirk	Association of Supervising Electrical Engineers.
E. B. Wedmore	British Electrical and Allied Industries Research Association.
F. Broadbent W. J. P. Orton C. Rodgers, O.B.E., B.Sc., B.Eng. J. B. Tucker A. J. L. Whittenham	The British Electrical and Allied Manufacturers' Association.
W. F. Bishop	Cable Makers' Association.
W. R. Rawlings E. A. Reynolds	Electrical Contractors' Association.
R. A. Ure	Electrical Contractors' Association of Scotland.
J. Howard-Blood E. B. Hunter W. H. Tuckey	Fire Offices Committee.
H. W. Swann	Home Office.
R. W. L. Phillips J. W. J. Townley	Incorporated Municipal Electrical Association.
E. W. Farr	Independent Cable Makers' Association.

REPRESENTATIVES OF THE INSTITUTION ON OTHER BODIES

The following is a list of representatives of the Institution on other bodies, and gives the dates on which they were appointed:—

Bristol University:

H. F. Proctor (8 Jan., 1925).

British Cast Iron Research Association:

E. B. Wedmore (25 Sept., 1924).

British Electrical and Allied Industries Research Association:

Council:
J. M. Donaldson, M.C. (18 Dec., 1930).
C. P. Sparks, C.B.E. (18 Dec., 1930).

British Electrical and Allied Industries Research Association (*continued*):

Sub-Committee on Connections to Large Gas-filled Lamps:
C. C. Paterson, O.B.E. (24 Oct., 1929).
B. Welbourn (24 Oct., 1929).

Sub-Committee on Earthing and Earth Plates:
S. W. Melsom (31 Jan., 1930).

British Electrical Development Association: Committee on Rural and Agricultural Electrification:

J. M. Donaldson, M.C. (20 Oct., 1927).
R. Grierson (20 Oct., 1927).

British Standards Institution:

Engineering Divisional Council:
P. V. Hunter, C.B.E. (11 April, 1935).
C. C. Paterson, O.B.E. (11 April, 1935).
R. T. Smith (22 Mar., 1934).

Electrical Industry Committee:
Lt.-Col. K. Edgcumbe, T.D. (5 Mar., 1925).
F. Gill, O.B.E. (21 May, 1914).
J. S. Highfield (21 May, 1914).
E. H. Shaughnessy, O.B.E. (23 Mar., 1933).
R. T. Smith (21 May, 1914).

Technical Committee on Electric Clocks:
E. B. Hunter (5 Dec., 1935).

Technical Committee on Electric Power Cables:
S. W. Melsom (10 Jan., 1930).

Technical Committee on Electric Signs:
L. Barlow (14 May, 1931).
R. W. L. Phillips (17 Feb., 1932).

Technical Committee on Electrical Accessories:
H. J. Cash (31 Mar., 1925).
F. W. Purse (31 Mar., 1925).

Technical Committee on Electrical Instruments:
Lt.-Col. K. Edgcumbe, T.D. (15 Feb., 1923).

Technical Committee on Electrical Nomenclature and Symbols:
C. C. Paterson, O.B.E. (8 Jan., 1920).

Technical Committee on Electricity Meters:
A. J. Gibbons, B.Sc.Tech. (28 Mar., 1930).
S. W. Melsom (21 Jan., 1926).
G. F. Shotter (28 Feb., 1929).

Technical Commmittee on Identification of Pipe Lines in Buildings:
R. Grierson (11 May, 1933).

Technical Committee on Lifts, Hoists, and Escalators:
H. Marryat (25 Oct., 1934).

Technical Committee on Overhead Transmission Lines Material:
P. Rosling (5 Mar., 1925).

Technical Committee on Wireless Apparatus and Components:
E. H. Shaughnessy, O.B.E. (30 Sept., 1925).

British Standards Institution *(continued)*:

Sub-Committee on Ceiling Roses:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).

Sub-Committee on Conduit Fittings:
H. J. Cash (18 May, 1927).

Sub-Committee on Connectors for Portable Appliances:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).
A. C. Sparks (16 May, 1935).

Sub-Committee on Connectors for Radio Apparatus:
R. W. L. Phillips (6 Jan., 1931).

Sub-Committee on Cut-outs for Radio Receivers:
S. W. Melsom (5 Dec., 1935).

Sub-Committee on Distribution Boards:
E. B. Hunter (25 Feb., 1927).
S. W. Melsom (25 Feb., 1927).

Sub-Committee on Instrument Transformers:
G. F. Shotter (22 Feb., 1934).

Sub-Committee on Lead Alloys for Cable Sheathing:
B. Welbourn (22 June, 1933).

Sub-Committee on Letter Symbols:
A. T. Dover (21 Nov., 1929).

Sub-Committee on Low-Voltage Cut-outs:
H. J. Cash (22 June, 1926).
E. B. Hunter (25 Feb., 1927).
S. W. Melsom (25 Feb., 1927).

Sub-Committee on Mains Supply Apparatus for Radio Receivers, etc.:
R. W. L. Phillips (11 Dec., 1930).
F. W. Purse (16 Oct., 1928).

Sub-Committee on Non-Ignitable and Self-Extinguishing Boards for Electrical Purposes:
S. W. Melsom (24 Oct., 1935).
E. Ridley (24 Oct., 1935).

Sub-Committee on Protected-type Plugs and Sockets:
H. J. Cash (26 Oct., 1932).
F. W. Purse (26 Oct., 1932).
A. C. Sparks (16 May, 1935).

Sub-Committee on Radio Interference from Trolley-Buses and Tramcars:
C. C. Paterson, O.B.E. (7 Nov., 1935).

Sub-Committee on Radio Nomenclature and Symbols:
Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.) (7 April, 1932).

Sub-Committee on Telephone and Radio Connectors:
R. W. L. Phillips (28 Feb., 1935).
A. J. L. Whittenham (28 Feb., 1935).

Sub-Committee on Tumbler Switches:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).

Sub-Committee on Wall-plugs and Sockets:
H. J. Cash (23 Jan., 1924).
F. W. Purse (23 Jan., 1924).
A. C. Sparks (16 May, 1935).

British Standards Institution *(continued)*:

Sub-Committee on Welding Plant and Equipment:
Major J. Caldwell, J.P. (26 Oct., 1933).

Panel on Graphical Symbols for Interior Installations:
J. R. Cowie (13 Nov., 1924).

Colliery Requisites Industry Committee:
C. T. Allan (3 July, 1924).

Technical Committee on Mining Electrical Plant:
A. C. Sparks (27 Mar., 1930).

Birmingham Regional Committee:
F. C. Hall.

Glasgow Regional Committee:
F. Anslow.

Manchester Regional Committee:
W. T. Anderson.

Newcastle Regional Committee:
S. A. Simon, B.A.

Sheffield Regional Committee:
M. Wadeson.

Technical Committee on Coal:
W. M. Selvey (19 Jan., 1928).

Technical Committee on Engine Testing Fittings:
W. M. Selvey (22 Oct., 1931).

Technical Committee on Engineering Symbols and Abbreviations:
A. T. Dover (21 Nov., 1929).

Technical Committee on Fans:
R. O. Kapp, B.Sc. (22 Oct., 1931).

Technical Committee on Land Boilers:
W. E. Highfield (2 July, 1931).
W. M. Selvey (7 April, 1932).

Technical Committee on Larch Poles:
B. Welbourn (21 Jan., 1932).

Technical Committee on Pipe Flanges:
W. M. Selvey (14 April, 1921).

Technical Committee on Pump Tests:
R. S. Allen (2 July, 1931).

Technical Committee on Railway Signalling Apparatus:
A. F. Bound (24 Oct., 1929).

Technical Committee on Rating of Rivers:
G. K. Paton (20 Oct., 1927).

Technical Committee on Rubber Belting:
C. Rodgers, O.B.E., B.Sc., B.Eng. (5 Jan., 1928).

Technical Committee on Methods of Test for Dust Extraction Plant:
C. L. Blackburn, B.A. (25 Oct., 1934).

Technical Committee on Traction Poles:
T. L. Horn (4 Feb., 1926).

Sub-Committee on Boiler Accessories:
W. M. Selvey (7 April, 1932).

British Standards Institution (*continued*):

Sub-Committee on Boiler and Superheater Tubes:
W. M. Selvey (7 April, 1932).

Sub-Committee on Boiler Fittings:
W. M. Selvey (7 April, 1932).

Sub-Committee on Water-Tube Boilers:
W. E. Highfield (2 July, 1931).
W. M. Selvey (7 April, 1932).

Sub-Committee on Portable Railway Track:
R. T. Smith (25 Oct., 1928).

Illumination Industry Committee:
Lt.-Col. K. Edgcumbe, T.D. (28 Feb., 1924).
P. Good (28 Feb., 1924).
H. W. Gregory (26 Oct., 1933).
Prof. J. T. MacGregor-Morris (28 Feb., 1924).

Building Industry, National Council for: Advisory Committee on Building Acts and Bye-laws:
F. W. Purse (20 Oct., 1932).
H. T. Young (20 Oct., 1932).

City and Guilds of London Institute:

Advisory Committee on Electrical Engineering Practice:
Prof. E. W. Marchant, D.Sc. (22 June, 1933).

Advisory Committee on Electrical Installation Work:
Prof. S. Parker Smith, D.Sc. (20 Oct., 1927).

Advisory Committee on Telecommunications:
E. H. Shaughnessy, O.B.E. (22 Oct., 1931).

Fellowship Committee:
W. H. Eccles, D.Sc., F.R.S. (19 April, 1928).

Council for the Preservation of Rural England:
J. M. Kennedy (10 Jan., 1929).

Electrical Association for Women:

Council:
A. P. M. Fleming, C.B.E., M.Sc. (18 Dec., 1924).

Committee for Training of Women Demonstrators:
E. E. Sharp (5 Nov., 1931).

Engineering Joint Council:
J. M. Donaldson, M.C. (11 Feb., 1932).
P. V. Hunter, C.B.E. (8 Mar., 1934).

Imperial College of Science and Technology: Governing Body:
W. M. Mordey (12 April, 1923).

Imperial Minerals Resources Bureau Conference: Copper Committee:
B. Welbourn (18 Sept., 1919).

Institute of Industrial Administration: Examinations Advisory Council:
A. P. M. Fleming, C.B.E., M.Sc. (25 Oct., 1934).

Institute of Metals: Corrosion Research Committee:
W. M. Selvey (19 July, 1923).

Institution of Civil Engineers: Engine and Boiler Testing Committee:
R. A. Chattock (19 Oct., 1922).
C. P. Sparks, C.B.E. (19 Oct., 1922).

International Association for Testing Materials:
J. M. Kennedy (5 July, 1928).

International Illumination Commission: British National Illumination Committee:
Lt.-Col. K. Edgcumbe, T.D. (27 Nov., 1913).
P. Good (18 Sept., 1919).
H. W. Gregory (26 Oct., 1933).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).
J. W. J. Townley (16 May, 1935).

Joint Fuel Committee:
R. A. Chattock (7 Jan., 1932).
C. P. Sparks, C.B.E. (7 Jan., 1932).

Leeds Municipal Technical Library Committee:
T. B. Johnson (9 Mar., 1932).

Loughborough Technical College: Advisory Committee:
Ll. B. Atkinson (11 April, 1929).

Metalliferous Mining (Cornwall) School: Governing Body:
L. A. Hards (1 Dec., 1927).

National Physical Laboratory: General Board:
C. C. Paterson, O.B.E. (3 Nov., 1932).
J. M. Donaldson, M.C. (7 Nov., 1935).

National Register of Electrical Installation Contractors:
H. J. Cash (12 Mar., 1931).
P. V. Hunter, C.B.E. (18 Feb., 1926).
W. R. Rawlings (18 Feb., 1926).
W. M. Selvey (18 Feb., 1926).

National Smoke Abatement Society:
H. C. Lamb (26 Oct., 1933).
C. D. Taite (26 Oct., 1933).

Professional Classes Aid Council:
P. F. Rowell (20 April, 1928).

Royal Engineer Board:
W. B. Woodhouse (19 Mar., 1925).

Royal Society:

National Committee on Physics:
C. C. Paterson, O.B.E. (6 Nov., 1930).

National Committee on Radio-Telegraphy:
E. H. Rayner, M.A., Sc.D. (9 Nov., 1933).
E. H. Shaughnessy, O.B.E. (6 Nov., 1930).

Science Museum, South Kensington: Advisory Council:
W. M. Mordey (10 April, 1930).

Town Planning Institute: Committee on Overhead Transmission Lines:
J. M. Kennedy (7 April, 1932).

Union of Lancashire and Cheshire Institutes (Panel for Engineering):
A. P. M. Fleming, C.B.E., M.Sc. (28 Feb., 1924).
Prof. Miles Walker, M.A., D.Sc., F.R.S. (28 Feb., 1924).

University College, Nottingham: Electrical Engineering Advisory Committee:
A. D. Phillips (23 Feb., 1933).

War Office Mechanization Board:
W. H. Eccles, D.Sc., F.R.S. (19 Jan., 1928).

Women's Engineering Society:
A. P. M. Fleming, C.B.E., M.Sc. (25 Sept., 1924).

World Power Conference (British National Committee):
R. T. Smith (1 May, 1930).

ELECTIONS AND TRANSFERS

At the Ordinary Meeting of the Institution held on the 7th November, 1935, the following elections and transfers were effected:—

Elections

Associate Members.

Beckett, David Richardson.
Benham, Cedric Minett, B.Sc.
Brunnen, John Ewart.
Burnham, Thomas Hall, B.Sc.
Davies, Trevor Hewitt.
Fells, Aubrey.
Freeland, Charles, B.Sc.
Goldschmidt, Prof. Rudolf, D.Eng.
Halliday, Donald Herbert, B.Sc.
Jubb, Brian, B.Sc.(Eng.).
Kirke, Harold Lister.
Nicholls, Walter James, B.Sc.
Olliver, Charles Wolfran.
Perkins, David, B.Sc.
Price, Thomas Wheatley, M.A.
Rae, Robert Bannerman.
Sandes, James Hector G., B.E.
Shields, Alfred Victor.
Taylor, Charles Allison, B.Sc.(Eng.)
Tyson, Thomas Gerald.
Westbrook, Ronald Porteous, B.Sc.

Companion.

Maurice, Helen Monica (Miss).

Associates.

Ashton, William Harold.
Batson, Henry George.
Brailsford, Arthur.
Diggle, John.
Douglass, Leslie.
Matthews, Stephen John.

Graduates.

Allerston, Pinder.
Ashe, Thomas Stuart, B.Sc.
Aziez, Mohamed Idrose.
Benington, Leslie William.
Bilton, Joseph.
Bliss, John Llewellyn.
Blomfield, Frederick William R.
Broadbent, Eric.
Buchanan, Bryant Lindley, B.A.
Craig, William Macderment.
Cronin, William, B.E.
Dabbs, Stanley Walter.
Davies, Reginald John C.
Dixie, John William.
Fletcher, Beey Peter C., B.Sc.
Flint, Henry Albert, B.Sc. (Eng.).
Fogg, George Harrison.
Frederick, Frederick Hubert.
Hare, Henry Arthur.
Hibberd, Geoffrey William, B.Sc.(Eng.).
Howarth, John Gill.
Hoy, William Thomas.
Jones, Norman William.
Kinkead, Robert Louis.
Leek, Thomas William.
Logie, Alexander Vallance, B.Sc.
Lord, Robert Frederick.
McBride, Maurice Graham, B.Sc.
McLellan, Charles Windlow.
Mills, William Harold.
Minter, Geoffrey.
Oram, Gavin Charles.
Palmer, Ernest Henry.
Picken, Donald Allsopp.
Rush, James Edwin.
Spencer, Frederick Elliot V.
Stewart, Christopher Harry.

Graduates (continued).

Wass, Charles Alfred A., B.Sc.
Welsh, Kenneth John, B.Sc.
Whyte, Allan McGillivray.
Wilson, Leslie John.
Woods, Donald.

Students.

Adams, Jack Stanley J.
Baker, William Ernest.
Birmingham, Murrough.
Burton, Frederick Ernest.
Connor, Frederick William.
Copson, Bernard Stephen.
Cox, Ronald Edgley.
Cummings, William Charles F.
Dawson, Arthur.
Dean, Gordon Stewart H.
Erlangsen, Harry Christopher.
Fearon, John Henry.
FitzPatrick, Christopher George.
Foy, Bernard George.
Grant, Maurice Ivor F.
Gray, Dudley Maurice.
Grundy, Bernard.
Hadaway, Harry William.
Ham, Tom Edgar G.
Harrod, John Berrison.
Hartshorne, Donovan Jesse.
Hodge, Paul George W.
Hunt, Donald Edwin.
Ince, Stanley Thomas.
King, George.
Krüger, Stefan.
Lawyer, Darabshah Jehangirsha.
Little, Alfred William G.
Longford, Charles Geoffrey.
Lovell, Wilbur Esh.
Lucas, Ernest Harold P.
MacDiarmid, Stuart Campbell.
McLachlan, Ronald Clephane.
May, Frederick Robert.
Meher-Homji, Jal Ardeshir.
Monahan, Thomas Francis.
Oldham, Hugh William, B.A.
Oswald, Joseph William.
Padaki, Seshagirirao Sreenivasarao, B.E.
Pearson, Philip Meredith.
Pipkin, Frederick Ernest R.
Reid, Frank Emerson.
Richards, Douglas John G.
Robinson, Allen Charles.
Rowe, Charles Vivian.
Rowe, Lester Fredrick.
Rumsey, Robert William.
Scott, Walter Harry.
Sekhar, Mysore Srikantiah C.
Sheth, Surendrabhai Lalbhai.
Smith, Ivor Ferguson.
Taylor, John Barker.
Thomas, Ivor Lewis.
Thomson, Mervyn George.
Tipler, Laurence Samuel.
Voltchaneski, Rostislav.
Wallace, Frank Donald.
Watts, James Albert.
Whyte, David Hector.
Wilson, Stanley.
Winckworth, John Wadham.
Yule, George Henry.

Transfers

Associate Member to Member.

Brazel, Claude Hamilton, Major, M.C.
Chaytor, Arthur Reginald.
Giacomuzzi, Luciano, Dott.Ing.
Holt, Frank Bertram.
Hood, Tom.
Jones, Edward.
Lawton, Frederick William.
Lea, Norman, B.Sc.
Leak, Basil Widenham.
Mirrey, James, B.Sc.
Moss, Ernest William.
Nancarrow, Frederick Ernest.
Robinson, Reginald.
Royle, William Arden.
Semenza, Marco.
Thorp, Edward William.
Wilkinson, Edgar Riley.

Associate to Associate Member.

Dixon, George, Major.
Graham, Robert Batthews.
Gray, Reginald Arthur G.
Hall, Harold.
Harral, Richard Harold.
Latham, Ashton.
Morgan, Frank.
Vlies, Henry Albert.

Graduate to Associate Member.

Abbott, Donald Hawkshaw.
Ahern, Patrick Joseph.
Ali, Syed Nazeer.
Arnot, Robert Starkey, B.Sc.
Ashworth, James Louis.
Bahree, Parkash Chand.
Baker, Charles Henry.
Barker, Harold Godfrey.
Barnes, David Errington, B.Sc.
Bentley, Desmond Mulock, B.Sc.(Eng.).
Blake, Robert Austin.
Bramwell, Eric Benjamin.
Calwell, James Edmonston M., B.E.
Cameron, Donald Lochiel, B.E.
Clunie, Matthew, B.Sc. (Eng.).
Collett, Eric John C.
Cunliffe, Edward Neil, B.Sc.Tech.
Earnshaw, Eric John, M.A.
Farrant, Dover Pearce.
Fawssett, Frederick Arthur.
Ferns, James Laurence, B.Sc.
Forster, Ernest William, B.Sc.
Graham, Arthur George.
Grant, Roderick Morison, B.Sc.
Headland, Henry, M.Sc.
Heaton-Armstrong, Louis John, B.Sc.
Herbert, John Ferguson, B.E.
Herwald, Nehemiah, B.Sc.
Hobbins, Henry.
Holden, Eric Kenyon, B.E.
Holmes, Cyril Thomas.
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Roberts, Frederick Walter.
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Graduate to Associate Member (continued).

Taylor, John Robert.
Thew, George Charlton, M.A.
Thorley, Thomas.
Vyas, Baldevbhai Motiram.
Walker, Alexander William P.
Whyte, William Langlands.

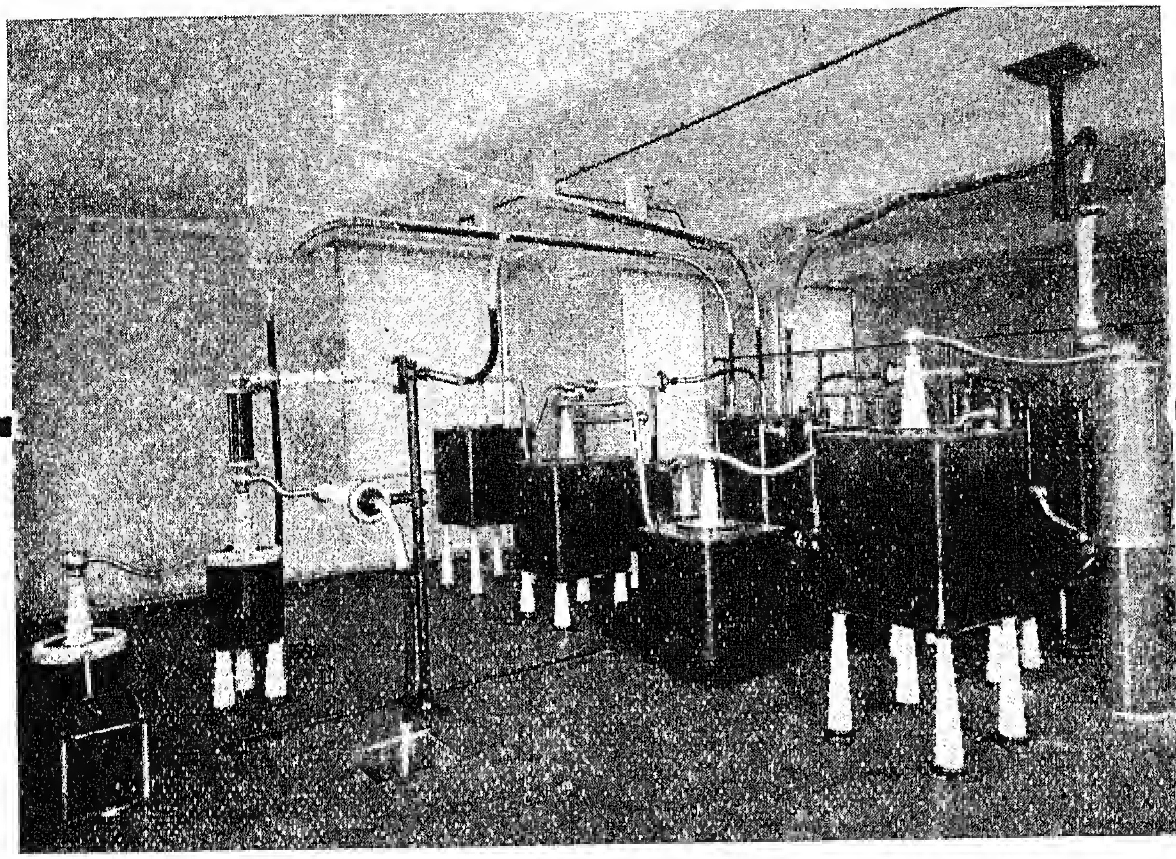
Student to Associate Member.

Barron, Donovan Allaway, B.Sc.
Buxton, Henry Fowler, B.Sc.(Eng.).
Ratcliffe, Maurice Vernon, B.Sc.(Eng.).
Williams, Leonard Ainslie, B.Eng.

In addition the following transfers have been effected by the Council:—

Student to Graduate.

Ballantyne, George Kello, B.Sc.(Eng.).
Bishop, Dudley Oswald.
Brand, Norman Frederick.
Brazel, Laurence Walton.
Brodie, John Lawrence S., B.Sc.(Eng.).
Bryant, Arthur Clifford.
Callow, John Hiner, B.Sc. (Eng.).
Clayton, Kenneth Bernarr, B.Sc.
Comer, Murray Frederick.
Cross, Donald Leslie.
Davis, John Hancock.
Dixon, Walter Harry.
Esson, George.
Farquhar, George.
Farrer, Sydney.
Ferry, Thomas, B.Sc.
Foot, George Helier.
Gill, John Archibald W., B.Sc.
Harvey, Henry Broderick.
Hedley, Oswald Chisholm.
Henchley, Terence Richard B., B.Sc.(Eng.).
Higgins, Geoffrey William, B.Sc.Tech.
Horsfield, Myles Vincent.
Hussein, Jawad.
Irvine, Donald Clotworthy.
Jennings, Frank, B.Sc. (Eng.).
Johnson, Alec Owen, B.Sc. Tech.
King, Geoffrey.
Lamb, David Amphlett.
Lazenby, Edward.
Matthews, Henry Charles H., B.Sc.
Mears, George Arthur, B.Sc.
Neill, Ian Reid, B.Sc.
Pipkin, Charles Harry B.
Presswell, Richard William, B.Sc.
Ratnam, Woolienellore Rangasawmy G., B.Eng.
Robinson, Bernard Cecil, B.Sc.
Sanders, John Campbell M., B.Sc.(Eng.).
Sanderson, Albert King.
Statham, Cyril David J., Ph.D., B.Eng.
Stephens, William.
Swann, Gilbert Frederick.
Wight, Robert Burton.



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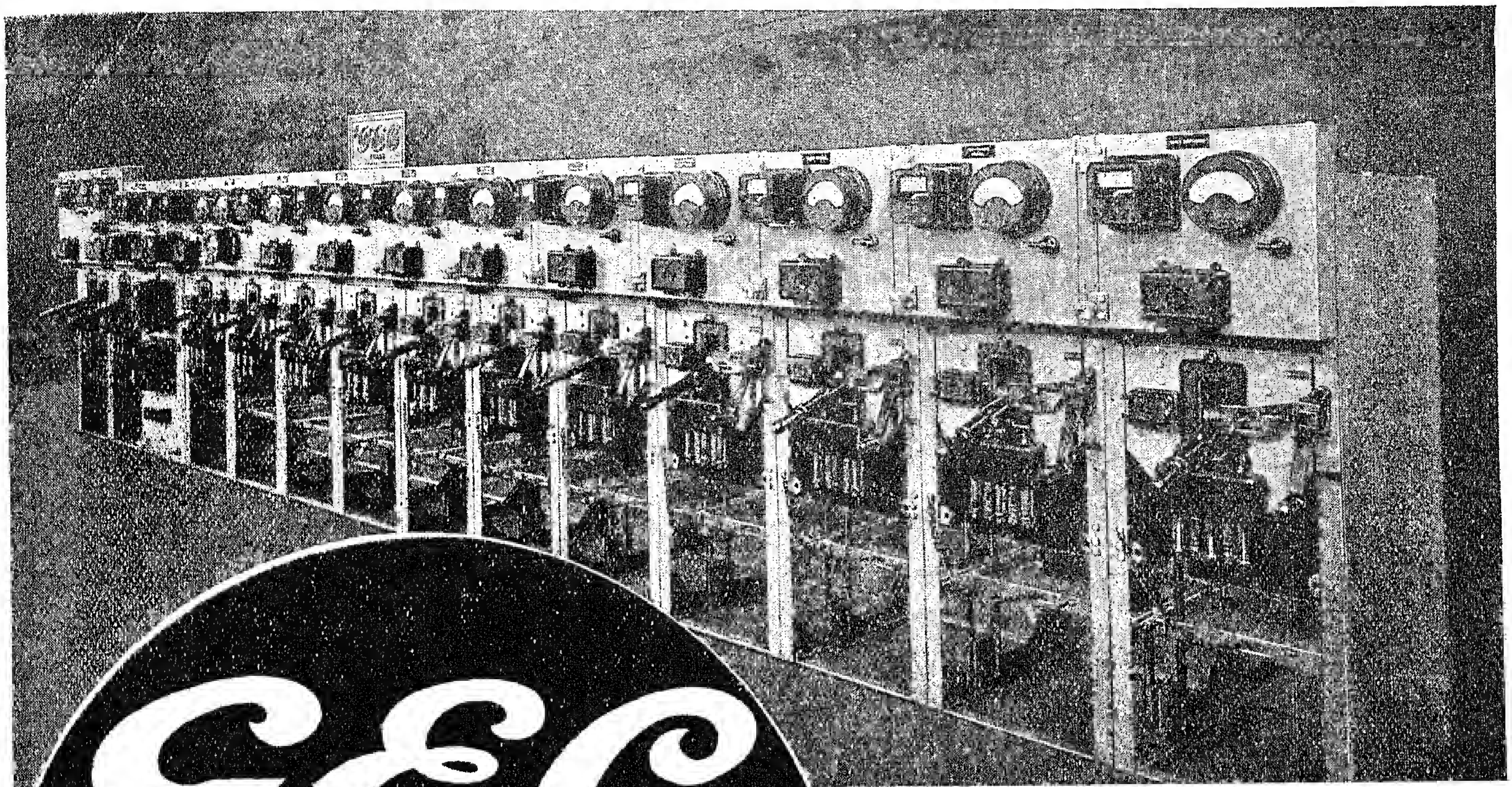

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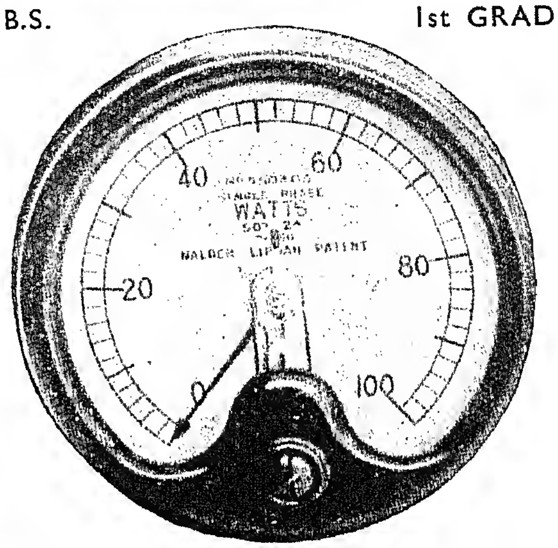

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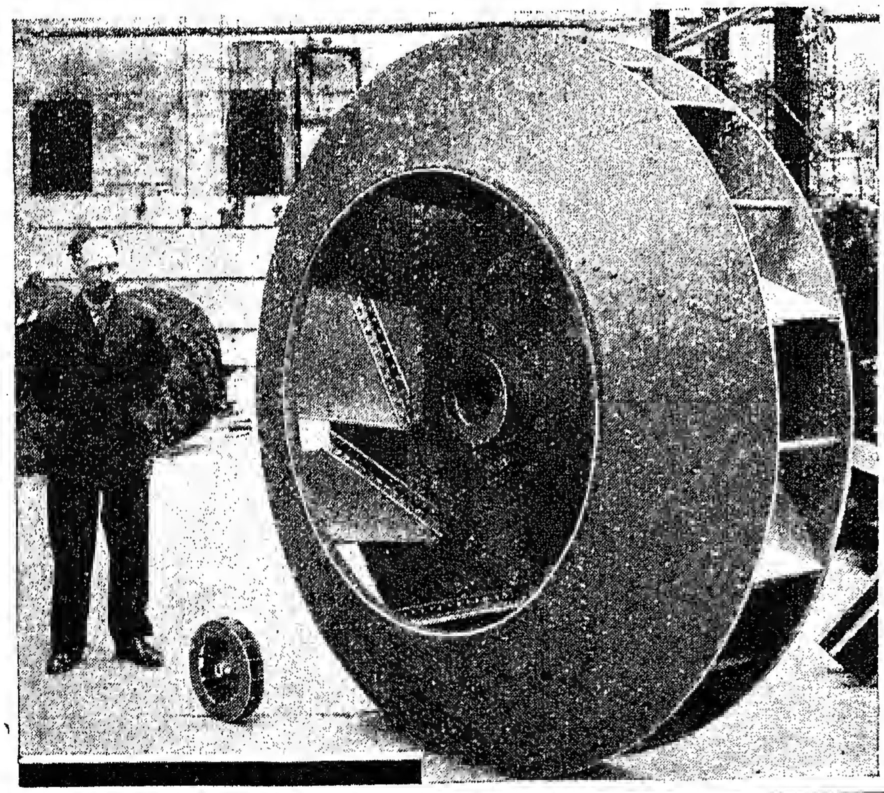

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